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PREFACE.

In this book the writer has made an earnest, and, he hopes, not altogether unsuccessful attempt to comprise, within the smallest possible space, and yet so as not to promote the intellect-demoralizing process of "mere cram," at least so much of the sciences of Magnetism and Electricity as shall enable students, who may have used fair diligence in their studies, to pass in the first class in the elementary stage of the Government Science Examinations. And further, shall not only enable them, and such other students as may have favoured him with their attention to achieve this result, but shall also, by the course they will have pursued, have caused them to have acquired those valuable educational results which always follow the systematic practice of reason, and the cultivation of accurate and truthful observation. With this view he has given far more attention to "theory" than will, for a book of its size, probably meet the approval of those who do not share his views. Not being able, within the space at his disposal, to treat all his subjects with equal fulness, he has, with the motive just stated, been induced to treat most fully the subjects of Magnetism and Frictional Electricity, the more especially as these subjects do not, as is the case with Voltaic Electricity, require a previous knowledge of Chemistry.

The writer, in conclusion, desires to express his indebtedness to the courtesy of Professors Guthrie and Barrett for their kindness in supplying him with copies of the papers issued to the Science Teachers who attended the recent course of Practical Instruction in Physics at South Kensington.

John Angell.

November, 1876.

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MAGNETISM AND ELECTRICITY.

CHAPTER I.

NATURAL MAGNETS OR LOADSTONE.

1. Early History of Magnetism.—Most educated people are now familiar with *magnets* and magnetism, through the medium of the schoolboy's magnet and the compass needle. Fabulous history attributes the discovery of magnetism to one *Magnes*, a Greek shepherd, who, watching his sheep on Mount Ida, first observed the attraction of the loadstone rock on his crook.

It is, however, more generally believed that the terms *magnet* and *magnetism* originated not in the name *Magnes* of its fabulous discoverer, but in that of *Magnesia*, a country in Lydia, where most probably it was first discovered. This theory is somewhat strengthened by the fact that the ancients frequently designated the magnet *Lapis Heracleus*, Heraclea being the capital of Magnesia. It is certain that the *natural magnet* or *loadstone* was known to the ancients during times of most remote antiquity, and it is equally certain that their philosophers treated it in the fanciful way in which all matters of science were then treated. Homer, Pythagoras, Aristotle, Pliny, regarded it as possessing miraculous qualities. Hippocrates treated it as a *purgative*. Thales and Anaxagoras regarded it as having a *soul*. Chinese travellers used the loadstone needle to guide them by land a thousand years before Christ. It is also recorded that the Chinese discovered, 400 years before Columbus, that the suspended magnetic needle did *not* point *true* north and south. Columbus, menaced by his crew, alarmed, among other things, because the compass needle deviated very considerably from its ordinary bearings, to such an extent, in fact, as to make them think that it was losing its "mysterious virtues," and that they would be left helpless on the vast and trackless ocean without any guide, tried to explain to his men that the direction of the compass needle was really not to the polar star, but to some fixed and invisible point. Frode, an Icelandic historian (born 1068), shows that the directive power of the needle and its use in navigation, were known in the eleventh century. Guizot of Provins, in a poem written about the middle of the twelfth century, speaks of the navigators saying "they possess a never-failing method by the virtue of the true marinière, an ugly and brown stone to which iron adheres of its own accord." He also says that the mode of using it consists in rubbing a needle on it (the marinière), and that the point of the needle thus prepared "turns just against the pole-star in dark nights, when neither star nor moon are seen." Dr. Gilbert first applied the term *poles* to the ends of the compass needle "because it points to the poles of the earth." Robert Norman constructed the first *dipping needle* in 1576. Mitchell invented the *Torsion-balance* about 1750; by means of this instrument Coulomb afterwards worked out the fundamental laws of magnetism. Though the ancients were familiar with the *attractive* power of the magnet, there is no clear evidence that they had any knowledge of its *repulsive* power.

2. The Science of Magnetism is the branch of *physical* science which treats of the nature and properties of *magnets*, natural or artificial, the various *phenomena* they exhibit, their action on each other and on external bodies or agents, the nature of the *force* by which these phenomena are produced, and the *laws* by which it is governed; it also treats of the magnetic phenomena exhibited by our own globe.

The science of magnetism also teaches the mode of *constructing* and *using* magnets and magnetic instruments; the means by which *magnetic force* is developed, and its relation to the chemical, physical, and mechanical forces of the universe.

3. Magnetism.—The term magnetism is also used to designate the *polar* force by which *magnets* and iron reciprocally *attract* each other, and by which *dissimilar* ends of *magnets attract*, but *similar* ends *repel* each other.

The most general and familiar phenomena of magnetism are those of *attraction* and *repulsion*, and its most familiar application that of the *compass needle.* Its modern application, however, in the form of the *telegraph,* and in the construction of various kinds of *automatic* apparatus, is now becoming almost universal.

Magnets possess among other properties the power of

1. Attraction and repulsion.
2. Exciting Magnetism, permanent or temporary.
3. Producing electric currents.
4. Producing light, heat, and sound (probably as a consequence of the last).
5. Acting on polarized light.

4. The Correlation of Magnetism, Electricity, Heat, Light, and Mechanical Force may readily be proved by the following experiment:—Procure and *connect* together, by means of silk covered copper wire, and arrange as shown in fig. 1 the following apparatus:—

1. A moderately powerful *galvanic battery* in action.
2. Two pieces of pointed *charcoal.*
3. A common iron *poker*, a *key*, and two or three iron *nails.*
4. A *voltameter*, consisting of a glass vessel and two glass tubes charged with *acidulated* water: the glass tubes and vessel being supplied with platinum wires and plates for transmitting the electric current through the liquid.

Connect one piece of *charcoal* with the first *copper* plate of the *battery*, and one platinum wire of the *volta-*

meter with the last *zinc* plate of the battery; connect the second platinum wire of the *voltameter* with the second piece of *pointed charcoal*, having previously coiled the *covered* wire round the "poker," close by which a small key and two or three small *iron* nails have been placed. Having completed these arrangements, bring the charcoal points together; immediately this is done, the two points will become intensely luminous, *shining* with great splendour, and evolving the most intense *heat*, the "*poker*" will immediately become a *magnet*, lifting or drawing, and thus communicating *mechanical movement* to the *key* and *nails*, which *move* and become *attached* to the poker, while, lastly, the *water* in the *voltameter* will *simultaneously* begin to bubble and *decompose* (chemically) into its constituent gases, *oxygen* and *hydrogen*, which collect in their respective tubes in the voltameter.

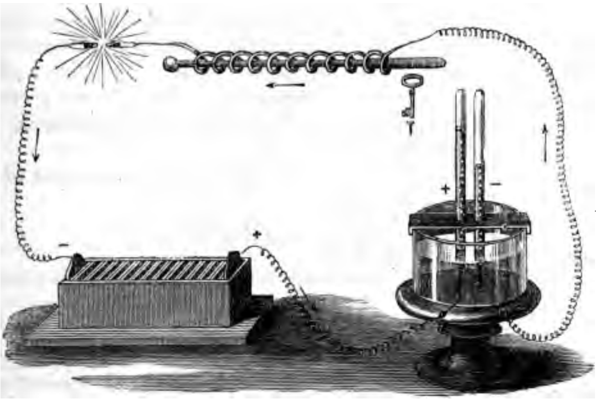

Fig. 1.—Arrangement, comprising galvanic battery, insulated copper wires, voltameter, iron poker and key, and two charcoal points, for showing the *mutual convertibility* of chemical affinity, electricity, magnetism, mechanical force, light, and heat.

5. This experiment clearly shows that the *electric*

current originating in the chemical action of the galvanic battery, and passing *out* at one end of the *battery* through the *wire*, the acidulated *water*, round the *poker* and through the charcoal points, and *back* again to the other end (pole) of the battery, is capable of exciting the various forces of chemical affinity—magnetism, mechanical force, heat, and light. It also proves that they are either so many *modifications* of the *same force*, or so many *modes of motion* produced by the same intrinsic force, or that *if different* forces they are most *intimately related.*

6. **A Magnet** is a body consisting usually of *iron* or steel, which has the property of *attracting* iron and other *magnetic* bodies, and which also possesses a certain *two-endedness* (polarity), in consequence of which two *similar ends* (poles) of two *magnets*, if brought within the necessary distance, *repel*, and two *dissimilar ends* (poles) *attract* each other. Magnets are either *natural* or *artificial.*

7. **A Magnetic Body** is a body, such as iron, which has the property of attracting and being attracted by *both ends* of a *magnet*, but which is *not repelled* by either end. The only *magnetic bodies* which possess decided *magnetic* properties are iron (including steel) and some of its compounds, and, in a much lower degree, chromium, cobalt, nickel, and manganese. Magnetic bodies do not attract or repel each other.

EXPERIMENT I.—Hold a piece of soft iron or steel, or some other substance, near first one end and then the other end of a compass needle. It attracts both ends of the needle. It is therefore a *magnetic body*.

EXPERIMENT II.—Hold another piece of steel or a piece of soft iron surrounded by a coil of copper wire, through which a current of electricity is passing (the copper wire being covered with a layer of silk), first to one *end* of the *compass needle*, and then the other. In this case the body under examination will be *attracted* by the one end and *repelled* by the other. The body is therefore a *magnet.* The *repulsive* power of a magnet is therefore a better proof of its being a magnet than its *attractive* power.

8. **Natural Magnets: Loadstones.**—Hitherto but one substance possessing the properties of a *magnet*

has been found in *nature,* that substance is a compound of iron, consisting of *iron* and oxygen, united in the proportion of *three atoms* of iron to *four* of oxygen, and is represented by chemists by the symbol $Fe_3\ O_4$. This oxide has been variously termed *magnetic oxide,* black oxide, and tri-ferric-tetra-oxide of iron. It is found largely in nature, forming a very pure ore of iron, from which the best iron is extracted. It exists abundantly in Sweden and Norway, where it forms entire mountains, and in some parts of America. Its colour varies from a reddish brown or black to a deep grey. It is about 4½ times as heavy as water. It crystallises in cubes, octohedra or dodecahedra.

9. This oxide acquires its power as a *magnet* by the *inductive* action of the earth exercised upon it when lying in its natural bed as rock or vein. A very small portion of this abundant oxide, however, possesses any marked power of attraction as a magnet, in general its powers in this respect being very feeble and almost inappreciable. *Loadstones* possessing any considerable degree of attractive power are very *rare;* the smaller loadstones also in general possess in proportion to *size* much greater power than the larger ones. *Natural magnets* in their *rude* state are exceedingly inferior in power to *artificial magnets;* they are seldom found sufficiently powerful to raise their own weight. Occasionally, however, small *native* or *natural* magnets have been found with extraordinary *attractive* power. Sir Isaac Newton *is said* to have possessed a small *natural magnet,* weighing about three grains, which was set and mounted in a ring which he wore, which would *lift* about 250 times its own weight. A *native magnet* presented by the Emperor of China to King John V. of Portugal, which weighed 38 pounds., was capable of supporting about five times its own weight, or about 200 pounds.

The effective power and usefulness of the *natural magnet* may be very greatly increased by a proper system of *mounting* with armatures (Art. 13).

Natural magnets of any size are rarely homogeneous or of uniform structure or power throughout. It therefore often happens that a portion of a *loadstone* cut from a larger one will support a greater weight than the large one itself.

Loadstone possesses the remarkable power of communicating its own properties *permanently* to *hardened* and *tempered steel* by the mere act of *rubbing*, and *temporarily* to *soft iron* by *contact* or even mere *proximity*.

10. Action of a Loadstone on Steel Filings.—EXPERIMENT.—Roll a piece of *natural magnet* or loadstone in fine iron or steel filings, and then withdraw it from the mass of the filings. A considerable portion of the iron filings will now be found adhering to the loadstone, by far the greater portion of which will be collected about two opposite points, as shown in the diagram (fig. 2). These points, in which the magnetic force *appears* to concentrate, are termed the *poles* of the loadstone, the line joining the middle of the poles is termed the *axis*, and the *middle* line perpendicular to the axis is termed the *neutral* line. At the true *neutral line* no filings adhere, but the *adherent* filings increase in quantity as we approach the poles. Sometimes the *loadstone* has several poles; in no case are the *poles* of the natural loadstone so well defined as those of an *artificial magnet*. In fact, all the properties of the magnet can be best demonstrated by means of *artificial* magnets. Each particle of the iron filings itself becomes a magnet (temporarily), that is, so long as it is under the influence of the *loadstone*. This is better shown with larger masses of iron, as shown in the next paragraph.

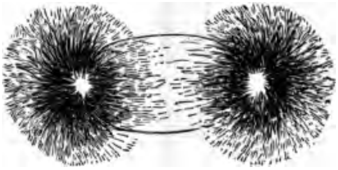

Fig. 2.—Showing IRON FILINGS clustered about the poles of a natural magnet or loadstone.

11. Action of a Loadstone on Small Masses of Iron.—

EXPERIMENT—Cut a piece of *loadstone* into a bar, and either supporting in the hand or on a suitable stand, bring *first* one light steel or iron article, as a ring or needle, into contact with it, the needle or ring will adhere to some portion near the end of the *loadstone;* next bring a second into contact with the last article, and another with it, and so on, they will adhere to each other and the magnet until their weight exceeds the *portative* force of the loadstone, each piece of iron not only itself becoming a *magnet* under the influence of the loadstone (that is by *induction*), but communicating its *magnetic* properties to the second, and so on.

This experiment is, however, best performed with an *artificial bar magnet,* the whole series forming the *magnetic chain,* as shown in fig. 3.

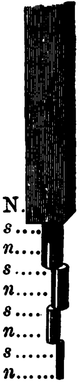

Fig. 3.—MAGNETIC CHAIN, consisting of a bar magnet and a series of pieces of soft iron adhering together, under the influence of magnetic induction.

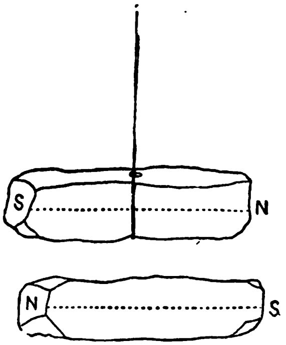

Fig. 4.—TWO BARS OF LOADSTONE, showing north and south poles and axis; also the mutual action of the poles on each other.

12. Action of One Loadstone on Another.—EXPERIMENT:—1. Suspend a bar of *loadstone,* cut so that its *poles* are at the end of the bar, by a fibre of silk tied round the middle of the bar in such a way that it shall be suspended horizontally (as shown in fig. 4), with perfect freedom of motion in every direction.

2. Bring one end of second bar of *loadstone*, similarly cut, near one end of the suspended bar; it will be either *attracted* or *repelled.*

3. Bring the *other* end of the second loadstone near the *same* end of the suspended bar, and the previous action will be *reversed;* that is, if formerly *attracted* it will be now *repelled*, and if formerly *repelled* it will be now *attracted.*

4. Allow the suspended loadstone to take up its normal position when *freely* suspended, it will point in the direction of the *magnetic meridian*—that is, *nearly* north and south. Now place the second *natural magnet* immediately below (as near as possible), and it will be found that the suspended loadstone will, whatever be its position, only come to rest when its *north-seeking* pole is over the *south-seeking* pole, and its *south-seeking* pole over the *north-seeking* pole, of the lower loadstone.

13. Mode of Mounting Natural Magnets.—As previously stated, the effective power and usefulness of *loadstone* is greatly increased by a proper system of *mounting* with *armatures*. The following is the method adopted :—

1. Find the poles of the mass of loadstone by means of iron filings, as described in Art. 10, taking care to select for mounting those masses which have *two* poles *only.*

2. Grind the *faces* at the opposite ends of the mass of loadstone which contain the *poles,* flat and parallel by means of the lapidary's wheel, also trim the mass so as to make its other sides somewhat parallel for convenience in mounting.

3. Make two armatures of the shape shown in fig. 5 of *pure soft* iron, each *armature* to consist of a *vertical face* about ¼ inch thick (or less if a small magnet) and a projecting solid *foot* one inch thick, the

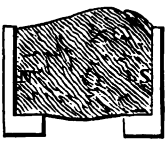

Fig. 5.—LOADSTONE, with soft iron armatures.

plates or armatures to fit on to the *polar* surfaces of the loadstone, as shown in the diagram.

4. Bind the tops of the armatures together by a brass cap with ring for suspending the magnet by, and the lower parts of the armatures by a brass band passing round them just above the projecting feet (see fig. 6).

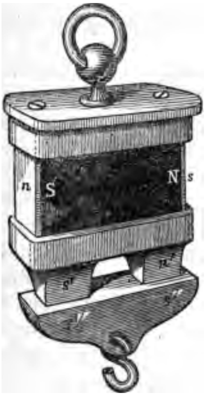

Fig. 6.--MOUNTED LOADSTONE (natural magnet and keeper). N, S, North and south poles of loadstone. *n*, *s*, Armatures. The feet of armatures, n', s', the same magnetism (by *induction*) as the *corresponding* poles of the loadstone. The ends of the keeper of *opposite* poles, n'' s' to the *feet* of the armature (by *induction*).

14. The Magnet may be strengthened up to a certain point, or its power preserved by the addition of a soft iron bar, termed a *keeper* or *lifter*, which is usually supplied with a hook or ring for supporting weights. It is said that if the keeper be gradually increased in weight, by the slow and gradual addition of small weights, the *portative* power of the magnet gradually increases up to a certain point, beyond which it is not possible to raise it, but that if the *keeper* be suddenly wrenched off it immediately loses the *additional* power thus gained.

15. Law of Magnetic Attraction and Repulsion. — *Magnetic poles of the same kind repel each other. Magnetic poles of opposite kinds attract each other.*

This law applies to all *kinds* of magnets, *natural* and *artificial*, electro-magnets included.

The general laws and phenomena of magnetism will be best discussed after the study of the construction, use, and properties of artificial magnets.

CHAPTER II.

ARTIFICIAL MAGNETS.

16. Artificial Magnets.—When a piece of steel, which has been properly hardened and tempered, is *rubbed* with a piece of *loadstone*, or by any other magnet, or when a current of electricity is passed round it by means of a coil of insulated wire, it becomes a more or less powerful *magnet;* such a magnet is termed an *artificial* magnet.

Artificial magnets are *permanent* or *temporary* according as they retain their magnetism or not, after being removed from the *source* by which they acquired it.

The most usual form of artificial magnets is that of a *bar* or a *horse-shoe.* When single they are termed *simple* magnets, when consisting of several joined together, so that their *similar* poles are *adjacent*, they are termed *compound* magnets; the latter are sometimes designated *magnetic batteries.* A magnetic battery is, therefore, simply a *bundle* of magnets with their *similar* poles placed together (see fig. 7).

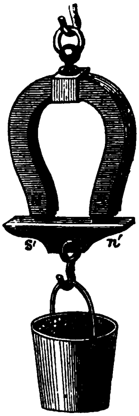

Fig. 7.-COMPOUND OR BATTERY HORSE - SHOE MAGNET, with loaded keeper or *lifter*. N, S, North and south - seeking poles of magnetic battery. *n,′ s,′* North and south poles (*induced*) of soft iron *keeper*, by the reaction of which the power of the magnet is preserved.

17. A Bar Magnet is simply a bar of cast-iron or steel properly hardened, tempered, and magnetised. It possesses *two poles*, a *magnetic axis*, and a *neutral line.* If the bar is too *hard*, its magnetism is *weak*, but is capable of being retained for a long time; on the contrary, if it be too soft (insufficiently hardened), it may be made much more powerfully magnetic at first, but it soon *loses* its power.

In order to *preserve* the magnetic

power of bar magnets when not in use, they are usually placed side by side, parallel to but *not touching* each other, and their ends joined by two movable pieces of soft iron, the keepers, as shown in fig. 8 (see Arts. 27 and 29).

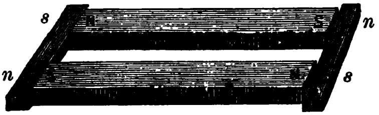

Fig. 8.—Two Bar Magnets and Keepers. N, S, North and south-seeking poles of magnets. *n*, *s*, North and South poles (*induced*) of soft iron keepers, which react upon and tend to *preserve* the magnetic polarity of the two bar magnets.

18. Polarity.—The term *polarity*, which is of almost constant occurrence in all works on Electricity and Magnetism, does not admit of very easy definition. It was defined by Professor Whewell as, "*opposite properties* in *opposite directions,* so exactly *equal* as to be capable of *neutralizing* one another." It is sometimes popularly described as a certain kind of *two-endedness.*

By *Magnetic Polarity,* as used by Faraday, is meant, "*opposite* and *antithetical* actions which are manifested at *opposite* ends of a *line* of force." (See Arts. 43 to 45).

19. Poles.—The poles of a magnet are the two points near the ends, at which the *attractive* and *repulsive* powers of the magnet are *apparently* concentrated. These powers *vary* greatly in different parts of the magnet, being *greatest* at its *poles*, and gradually falling in intensity towards the *middle,* where they totally *disappear.*

20. Consequent Points or Poles, or Consecutive Poles.—When a magnet is badly (*irregularly*) magnetised, it frequently contains three or more poles; that is, it possesses one or more poles besides those near its extremities. The term *consequent points* is applied to designate these *extra* poles (see figs. 16 and 25).

When a magnet possesses *three* or any *odd* number of poles, the *middle* pole is *opposite* to that of the two *terminal* poles. When it contains an even number of poles (but *more* than *two*) these poles are *alternately* North and South.

21. Neutral Line, or Magnetic Equator. — Every regular magnet contains *midway* between its two poles a *neutral line*, to which iron filings will not adhere, and at which it exercises no visible magnetic force.

22. Pure Soft Iron not Capable of Permanent Magnetization.

Experiment I.—1. Take a small piece of soft *iron* wire about two inches long; heat it to bright cherry *redness* in the fire or the flame of a spirit lamp; allow it to cool slowly; clean or brighten it up by rubbing with emery paper. 2. Now bring it near the ends of a permanent magnet, taking care it does not touch the magnet, or place a piece of paper between it and the magnet; then bring the needle into contact with the steel filings, which will now adhere, the iron wire having become a *temporary* magnet under the influence of induction. 3. Remove the wire from the vicinity of the magnet, all the steel filings will now fall away from the soft iron wire, it having ceased to be a magnet.

Experiment II.—Rub the same wire with the magnet. Immediately it is removed from the magnet it loses its power of *attracting* iron or steel filings, or of *repelling* either end of a light magnet.

23. Steel Capable of Permanent Magnetization.— Repeat experiments I. and II. with a similar piece of *steel* wire, or a thick sewing needle, or a small magnet made of watch spring which has been heated as described in the last section. Effects similar to those in the last case will be produced to those, *but* the *steel needle* or wire will now retain a *feeble* magnetic attraction for the iron filings *after* the magnet has been removed.

24. Effect of Hardening and Tempering on the Magnetization of Steel.

Experiment I.—Heat the needle or piece of watch spring to bright *redness*, and immediately plunge into cold water; it is now said to be *hardened*, and will have become as *brittle* as glass. The steel needle or watch spring now becomes magnetised with much greater difficulty, and much more feebly, but retains its magnetism much more permanently.

Experiment II.—After *hardening* the needle as in the last experiment, carefully clean or brighten its surface with emery paper, and place it on a hot iron bar or poker; it will first become slightly yellow, then, passing through various shades of yellow, light-brown, brown, purple, etc., will at last become of a watch spring blue, immediately on passing into which it should be dropped into cold water; it has now been *tempered.*

When thus *hardened* and tempered, the steel has lost its original brittleness, and acquired the properties of flexibility and elasticity, while retaining much of its newly-acquired *hardness.* Steel thus prepared has assumed the condition most suitable for the construction of good magnets. When *carefully* kept, such magnets retain their magnetism almost indefinitely. When prepared of *hardened* steel, they retain their magnetism even more permanently, but are much *more feeble* as magnets. When constructed of *soft* steel they are much *more powerful* at first but soon *lose* their magnetism. The student may readily prove these facts for himself as just shown (see Arts. 22, 23).

The varied conditions of the steel, in relation to magnetism, depend on altered conditions of its *coercive force.*

25. Broken Magnets.—Harden (but not temper) a piece of watch spring as described in Art. 24. *Magnetise* the hardened watch spring by drawing one pole of a magnet along its surface from one end to the other several times in succession. One end will thus acquire *north* and the other *south* magnetism. Break the magnet thus prepared (an easy operation, because of its great *brittleness*) into several pieces. On testing these pieces with a suspended compass needle, each *segment* will prove to be a

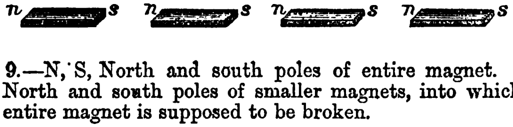

Fig. 9.—N, S, North and south poles of entire magnet. *n*, *s*, North and south poles of smaller magnets, into which the entire magnet is supposed to be broken.

perfect *magnet,* having both a *north* and *south* pole, the *two extremities* retaining their original polarity, as shown in the diagram, fig. 9. These effects will be produced altogether independently of the number or minuteness of the parts into which the magnet is broken. This would seem to show that each molecule of the broken mass permanently retains within itself its own original share of the magnetic fluids.

26. Theories of Magnetism.—Two *theories,* or rather *hypotheses,* are adopted for the explanation of the various facts and phenomena of magnetism:—

1. The *two-fluid* theory of Coulomb, which, from its simplicity and convenience of application, is the one more generally adopted.
2. The *electrical* (Ampère's) theory, which is perhaps most compatible with modern discovery (see Ampère's *Theory of Molecular Currents*).

27. Two-fluid Theory of Magnetism.—This *hypothesis,* invented by Coulomb, supposes: (1) that the *properties* of a magnet are due to the action of *two fluids,* an *austral* and a *boreal* fluid, present in *equal* quantities in the magnet, each of which is *self repellent,* but which are *mutually attractive* of each other; (2) that magnets are composed of an indefinite number of *minute* particles or *atoms,* each of which is a *complete magnet;* (3) that each *atom* of the magnet possesses an equal quantity of each of the *magnetic fluids* which, though capable of being separated from each other, are incapable of being *separated* or escaping *from* the atoms themselves; (4) that when the two fluids, the *austral* and the *boreal,* are *combined,* they *neutralise* each other, and are incapable, as in

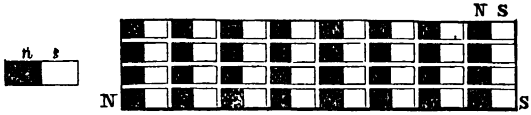

Fig. 10.—Showing distribution of north and south magnetic fluids about, but *inseparable* from, molecules of magnets. *n, s,* A single molecule or particle of magnet.

the case of ordinary steel or iron, of giving rise to *magnetic polarity;* (5) that when these fluids *are separated* from each other (though still *retained* in, and *inseparable* from, their respective *atoms*), they give rise to *magnetic polarity*, or, in other words, convert the body into a *magnet;* (6) that the act of *magnetising* such a body simply consists in the decomposing or separating (*in each of its constituent molecules* or *atoms*) by external means, its *neutral* magnetic into its elementary *austral* and *boreal* fluids; (7) that by *magnetic saturation* is simply meant the most complete permanent *separation* possible of these two fluids.

These views are supported by the facts, (*a*) that when one body is magnetised or converted into a magnet by another, the *magnetising* body *loses* none of its magnetic *power;* (*b*) that into how many particles soever a magnet be *broken*, each part remains a *complete*, though of necessity a proportionately feebler *magnet.*

28. The Theory of Two Fluids a mere Provisional Conception.—The student should, however, clearly understand that these views are purely *imaginary* and *provisional*, partaking of the nature of a mental *conception*, but not of a natural fact. And that their chief value arises from their giving a simple and *rational*, though not *proved*, explanation of important natural phenomena, at the same time that they tend to give unity to a group of natural facts, and assist in their more thorough investigation. He should also know that, up to the present time, we have not one iota of proof of the existence of any such *fluid* as either of the assumed *magnetic fluids.* With these reservations, however, the student will find the language and views of this theory of the greatest use, not in accurately expressing, but in seeing into and classifying, the phenomena of magnetism.

29. Theory of the Preservative Action of Armatures.—*Armatures* or *keepers* are pieces of *soft iron* used to connect the opposite ends of magnets, with the object of preserving their magnetic polarity. The north and south magnetic fluids (see Art. 27), upon the continued *separation* of which the magnetic *polarity* of the bars depends, tend slowly (according to the degree of *resistance* offered by their *coercive* force) to *reunite*, the bars slowly losing their polarity as the magnetic fluids *recombine.*

The *keepers* tend to prevent this *recombination* of the magnetic fluids, by themselves becoming magnets under the *inductive* influence of the bars, to the ends of which they are attached. The end of each keeper (*s*) adjacent to the north-seeking end of the bar becomes charged with *south-seeking boreal* magnetism (see Art. 27), and thus attracts the opposite magnetic fluid of the bar, and repels its own kind of magnetic fluid to the *opposite end* of the bar. The opposite ends (*s*) of the *keepers*, which are similarly acted upon by the *inductive* power of the bar magnets, also *react* in a similar manner upon the bars themselves, but with *reversed* poles. Their resultant action is thus the preservation of the power of the magnet during an almost indefinite period. (See Arts. 45 and 46.)

30. Coercive Force.—It has already been shown (Arts. 4 to 11) that a piece of pure soft *iron* immediately becomes *magnetised* under the influence of another *magnet*, or of an *electric current*, but as quickly loses its magnetism on being removed from its influence; also, that a piece of steel properly *hardened* and *tempered*, though it neither acquires magnetism so *quickly*, nor to the same degree, retains it much more *permanently* under similar circumstances. The cause of this difference in their behaviour, under these similar external conditions, is ascribed to their respective degrees of *coercive force.*

Coercive force may therefore be defined as that *force*, agency, or influence, by which in a particular body or substance the *austral* and *boreal* fluids resist *separation*, and by which, when separated, they resist *recombination.* It is *absent* or very *feeble* in *soft* iron, but very *powerful* in *hardened* steel. (See Arts. 22, 23, 24.)

31. Point of Saturation.—When a steel bar has been magnetised to the maximum intensity of magnetism it can *permanently* retain, it is said to be magnetised to *saturation.* Under the influence of powerful electro-magnets, a steel bar may be magnetised far beyond *saturation,* but it will afterwards, even under circumstances favourable to the retention of its magnetism, fall down to its point of *saturation.*

32. Magnetization of Steel Bars.—Steel bars may be magnetised (1) by rubbing *permanent* magnets from end to end along their surfaces; (2) by passing *voltaic* currents round them transversely to their axes, by means of insulated coils of wire (see fig. 1); (3) by means of *electro-magnets* used in place of the *permanent* magnets used in process 1; (4) by the *inductive* action of the earth's magnetism.

Three methods of magnetization by the *inductive* action of *permanent* magnets have been described.

(*a.*) Method of *single* touch.
(*b.*) Method of *separate* or *divided* touch.
(*c.*) Method of *double* touch.

33. Method of Single Touch.—Take a powerful *bar* magnet, or still better, *battery* of bar magnets, and draw one end or pole of the magnet from end to end along the bar to be magnetised, taking care *always* to move the magnet in the *same* direction along the bar. The end or pole of the steel bar, at which the pole of the magnet *leaves* the bar, will always be of the *opposite* magnetism to that of the magnetising magnet. That is, if the *marked* or *north-seeking* end of the magnet be used, the end of the steel bar *last* touched by it will be a *south-seeking* pole (see fig. 11).

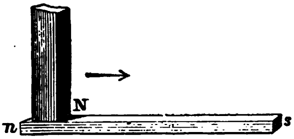

Fig. 11.—Showing Magnetization by Method of *Single Touch.* The end, N, of the magnet is successively drawn along the bar from *n* to *s*, where it is made to leave the bar; *s* therefore becomes the *south-seeking* pole.

This method is only suitable for the magnetization of small bars or compass needles.

34. Method of Separate or Divided Touch (Dr. G. Knight's method improved by Duhamel).—

1. Place the bar to be magnetised so that its ends shall rest on the *opposite* poles of two *equally* powerful bar magnets (see fig. 12).

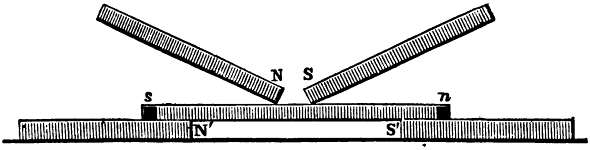

Fig. 12.—SHOWING MAGNETIZATION BY METHOD OF *Separate* or *Divided Touch.*

2. Take two other powerful bar magnets, and placing their *opposite* poles at the *middle* of the bars to be magnetised, so that the magnets themselves may make an angle of about 20° with the *horizon.*

3. Draw them *simultaneously from* the *middle* of the bar *to* its *ends* ten or twelve times, taking care each time the operation is repeated to raise the magnets from the bar while bringing them back to the middle of the bar.

Care must also be taken that the poles of the magnets used for *rubbing* the bar must be *similar* to those placed *below* them and *under* the bar. This method probably makes the most *regular* magnets, there being in it, as compared with other methods, less tendency to the formation of *consequent points.*

35. Method of Double Touch (Mitchell's method).—
1. Place the *supporting* magnets beneath, and the *rubbing* magnets on the *middle* of the bar to be magnetised, as in the method of *separate touch* just described, but do not let the *rubbing* magnets make an angle of more than 15° with the horizon (see fig. 13).

2. Place a small bit of wood or cork *between* the ends of the *rubbing* magnets, to keep their opposite poles permanently at the *same distance* from each other.

3. Move the magnets *simultaneously* backwards and

forwards along the entire length of the bar to be magnetised, moving them *alternately*, first to the one, and then to the other end of the bar, and taking care to move them an *equal* number of times along each half or end, and to *terminate* the rubbing at the *middle* of the bar.

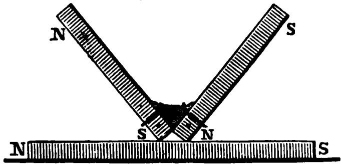

Fig. 13.—Showing Magnetization by method of *Double Touch.* The horizontal bar is supposed to rest on the *poles* of two powerful magnets, as in fig. 12.

This method produces the most *powerful* magnets, although it also tends to produce *consequent points.*

In each of these cases, *battery magnets* may be substituted, with advantage, for simple bar magnets.

36. Magnetization by the Electric Current.—Make a *right-handed* coil of insulated copper wire, as in figs. 1 and 14; place the steel bar or needle to be magnetised in its interior, either with or without the aid of a glass tube; connect the ends of the helix or coil respectively with the positive and negative poles of a voltaic battery at work.

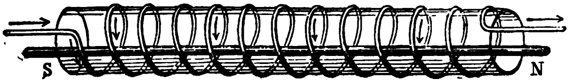

Fig. 14.—Dextrorsal (right-handed) Helix.

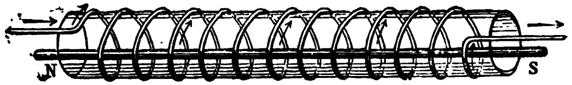

Fig. 15.—Sinistrorsal (left-handed) Helix.

Immediately this connection is made, an *electric current* will be established in the wire, and the needle or bar will become *magnetised*, its *north-seeking* end being situated at the end of the coil at which the current of *positive* electricity *leaves* the coil, that is, at the end of the coil which is connected with the *zinc* plate of the battery. If a *left-handed* coil (fig. 15) be used, the *north-seeking* end of the bar will be found at the opposite end of the coil, or that which is connected with the *copper* or *platinum* plate of the battery.

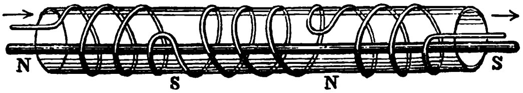

Fig. 16.—Mixed Helix, arranged for consequent points.

37. The following method of magnetization by means of the electric current, first adopted by Arago and Ampere, is frequently employed by makers of magnets:—

Bend a few feet of the insulated copper wire, through which a moderately powerful voltaic current is passing, into a short coil, into the 'interior of which place the bar or horse-shoe to be magnetised, and move the coil along from one end to the other, as shown in fig. 17, always *re*commencing at the same end of the bar.

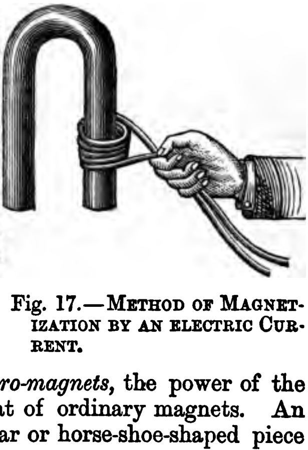

Fig. 17.—Method of Magnetization by an electric Current.

38. Magnetization by Electro - Magnets.—Magnets are now very generally prepared by means of *electro-magnets*, the power of the latter greatly exceeding that of ordinary magnets. An electro-magnet is simply a bar or horse-shoe-shaped piece of *soft iron*, round which a current of electricity is passed by means of a coil of insulated copper wire.

The following is the method of magnetization by means of electro-magnets generally adopted by makers of magnets:—The steel bar to be magnetised is carefully and *regularly* drawn from *end* to *end* alternately, first over one *pole*, and then *back* again in the *opposite* direction over the *second pole* of an electro-magnet fixed in a piece of board, as shown in fig. 18. Each *pole* of the electro-magnet in this case develops the *opposite* magnetism to its own, at the end of the bar at which its stroke ceases.

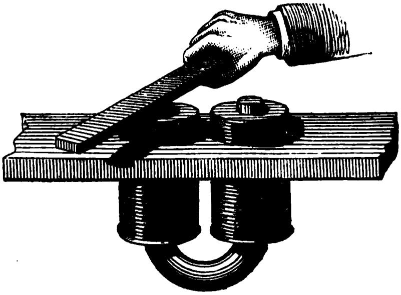

Fig. 18.—Method of Magnetization by an Electro-Magnet.

39. Strokes in *opposite* directions over the two *dissimilar* poles of the electro-magnet thus tend to develop *similar* magnetism in the bar, or, in other words, to magnetise the bar in the *same* way.

When, however, a very powerful magnet has to be prepared, the force required to move it along the pole of the electro-magnet becomes inconveniently great, and the appearance of the bar becomes spoiled by scratching. In such cases makers now usually employ Arago and Ampere's method of magnetising by means of the electric current, described in Art. 37.

40. Magnetization by the Inductive Action of the Earth.—Suspend the bar to be magnetised in *magnetic meridian*, that is, so that it shall point in the direction, nearly north and south, of the compass needle, and also in the *line of dip* (about 70° with the horizon). If the suspended bar be of *soft iron*, and steel filings be brought into contact with it, they will be immediately attracted, and will adhere. If, however, the bar be of hardened steel, its magnetism will require a few minutes to arrive at its *maximum* intensity of magnetism, because of its *coercive* forces causing it for a short time to resist magnetization. If the suspended bar be struck smartly several times in rapid succession, the process of magnetization is quickened, and the magnetism rendered more permanent.

41. If the bar, being of *soft iron*, be twisted or bent while in its state of temporary magnetism, it tends to retain a portion of its magnetism, thus becoming a weak permanent magnet.

The *magnetization* here described is brought about by the *inductive* action of the *earth*, which is, therefore, practically a *magnet.*

42. Magnetic Field.—The term magnetic field was used by Faraday to designate the entire region or space through which the magnetic force acts or is diffused.

43. Lines of Magnetic Force.—

EXPERIMENT.—Place a flat sheet of stiff cartridge paper, or a plate of glass, immediately over a magnet, so as to be as nearly as possible in contact with it; if glass, it may rest upon the magnet; scatter *iron filings*, by means of a sieve, over the surface of the paper or glass, then gently tap the same; the iron filings will arrange themselves in certain symmetrical and well-defined *lines* or *curves*, designated by Faraday, *lines of force.*

The iron filings attach themselves *end* to *end* in their *longest dimensions*, that is, lengthwise along these lines.

If a small, but freely suspended magnetic needle, be brought near the magnet, it will set itself *along* these *lines of force.*

The general character of these curves or lines of magnetic force varies with the action of magnets on each other. The following figures show the *lines of force*, indicated by the arrangement of iron filings:—

(1.) About a single bar magnet.

(2.) About two parallel bar magnets, with their *dis*similar poles adjacent.

(3.) About two parallel bar magnets, with their similar poles adjacent.

(4.) About two bar magnets, with *dis*similar poles placed *end* to *end.*

(5.) About two bar magnets, with similar poles placed *end* to *end*.

(6.) About a horse-shoe magnet.

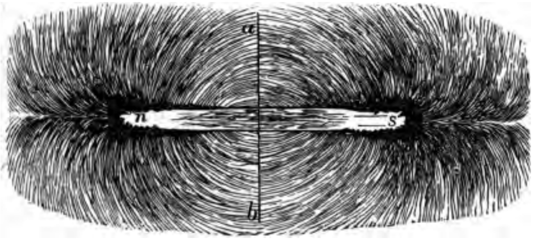

Fig. 19.—Iron Filings about Bar Magnet, showing *lines of magnetic force.* *n*, *s*, North and South Poles; *a*, *b*, neutral line or Magnetic Equator.

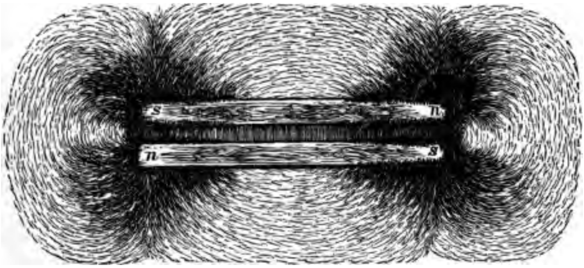

Fig. 20.—Iron Filings, showing *lines of force* about two parallel Bar Magnets, with their *contrary* poles adjacent.

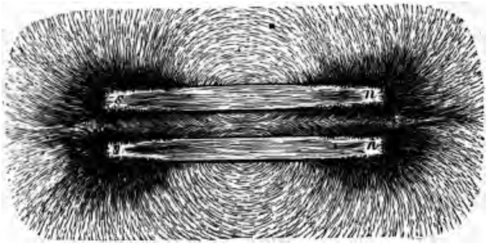

Fig. 21.—Iron Filings, showing *lines of magnetic force* about two parallel Bar Magnets, with their *similar* poles adjacent.

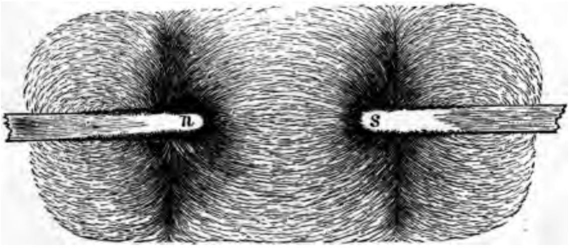

Fig. 22.—Iron Filings, showing *lines of force* about the two *dissimilar* poles of two Bar Magnets, placed *end* to *end*.

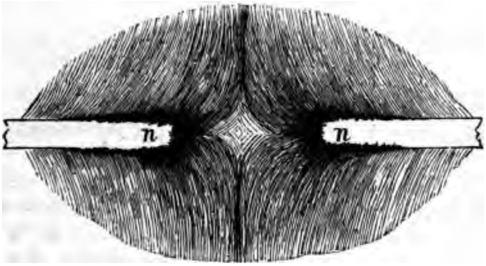

Fig. 23.—Iron Filings, showing *lines of magnetic force* about the two *similar* Poles of two Bar Magnets, placed *end* to *end*.

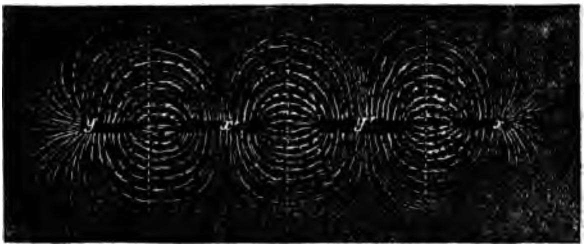

Fig. 24.—Bar Magnet, with Iron Filings about *consequent points*. x, y, North and South Poles; x', y', consequent points. The dotted *straight* lines show neutral lines or *Magnetic Equators*.

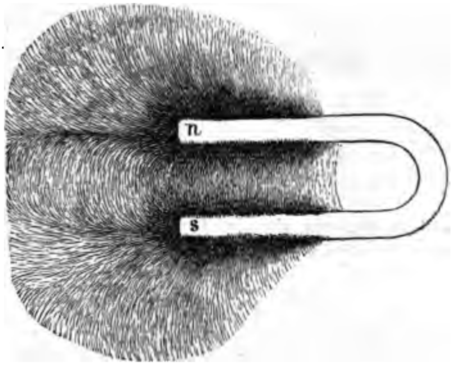

Fig. 25.—IRON FILINGS, showing *lines of force* about the two poles of a Horse-shoe Magnet.

44*. Faraday defined a *line of magnetic force* to be "that line which a very small needle describes when it is so moved in any direction correspondent to its length, that the needle is constantly a *tangent* to the *line of motion;*"—or as "that line along which, if a *transverse* wire be moved in either direction, there is *no* tendency towards the *formation of any current* in the wire, whilst if moved in any other direction there *is* such tendency." The direction of these lines *about* and *between* ordinary magnets is easily represented, in a general manner, by the use of *iron filings.*

45. Magnetic Induction is the separation of the magnetic fluid which takes place when a piece of iron or steel is brought within a magnetic field; or, in other words, is the conversion of an ordinary piece of iron or steel into a magnet by its being brought into contact, or even into nearness or proximity, to a magnet. The nearer such mass of iron is brought to the magnet, the more powerful is the magnetism, or rather the *magnetic polarity,* induced. (See Arts. 11, 17, 29, and 40).

If a piece of iron, *not in contact* with the magnet, be magnetised by *induction*, the end nearer the pole of the *inducing* magnet will be of the *opposite* polarity to that of the magnet, while the end more *remote* from the magnet will be of *similar* polarity to that of the *nearer* pole of the magnet.

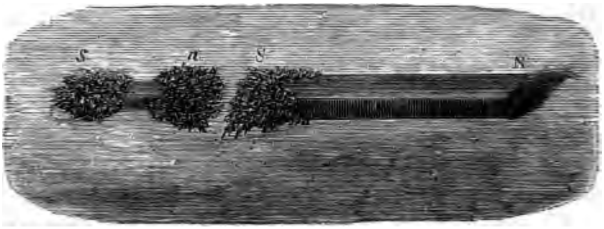

Fig. 26.—SHOWING MAGNETIC INDUCTION. N, S, North and South Poles of a Bar Magnet. *n*, *s*, North and South Poles of a piece of soft iron magnetised *inductively* (at a distance) by the permanent bar magnet. The *magnetised* state of the *soft iron* bar is shown by the adhesion of the iron filings.

If the mass of iron be in contact with the *inducing* bar magnet, it will practically become part of the magnet, simply extending its length, and its farther end being of the same polarity as that end of the magnet to which it is joined.

Magnetic induction not only takes place through intervals of air, but is also exerted through plates of glass, wood, cardboard, and other solid bodies of some thickness.

46. Magnetic Induction always gives rise to Repulsion as well as Attraction.—When a magnet is brought near a piece of freely suspended soft iron it invariably attracts it, that is, the mass of iron moves towards the magnet; but the iron is also *repelled*, though the *repulsion* is in this case concealed or masked by the *greater* force of *attraction*.

This phenomenon arises from the operation of the law, that *the force of attraction and repulsion vary inversely as the squares of the distances*. Thus, if the *marked* end of a magnet be brought to a distance of a quarter of an inch from a soft iron ball one inch in diameter, it will, by *in-*

duction, separate its magnetic fluids, the *boreal* fluid being *attracted* to the *nearer* side of the iron ball, that is, to the side nearer the magnet; and the austral fluid being *repelled* to the farther side of the iron ball. But the particles of the iron ball nearest the magnet are only $\frac{1}{4}$ inch distant, while those most remote on the farther side of the ball are $\frac{5}{4}$ inch distant, from the magnet; therefore the force of *attraction* will be to that of repulsion in this case (so far as these particles are concerned) as 5^2 is to 1^2; or, in other words, the force of *attraction* will be twenty-five times as *great* as that of *repulsion*.

The resultant *attraction* of the iron ball by the magnet is thus the *difference* between the forces of *attraction* and *repulsion* actually at work.

47. Action of a Bar Magnet on a series of Compass Needles, or Small Magnets suspended immediately above it.—When a series of small magnets are freely suspended above a large bar magnet, as shown in fig. 27, they assume the respective positions therein indicated. The *suspended* magnets near the poles of the *larger* magnet dip almost perpendicularly, so that the *north* pole of the smaller magnet at the one end dips to the *south* pole of the attracting magnet, and the *south* pole of the magnet suspended at the opposite end of the bar dips to its north pole.

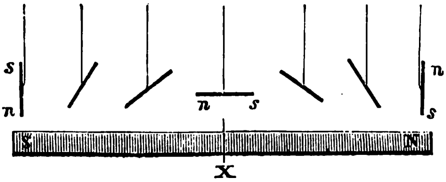

Fig. 27.—Showing action of Powerful Bar Magnet on a series of Small Magnets suspended by threads. N, S, and *n*, *s*, North and South Poles. X, *Neutral line* or Magnetic Equator.

The magnet suspended over the *middle* of the large magnet, being acted on equally at its opposite ends by equal forces of attraction and repulsion, comes to rest in a position of *parallelism* to the bar.

48. Action of Magnets on each other.—*Case* 1. If two bar magnets be placed side by side, so that the *north* pole of the one shall lie on the *north* pole of the other, also the *south* pole of the one on the *south* pole of the other, their *portative* and *attractive* powers will be increased, that is, they will *support* a *greater* weight, and attract with greater force; but their combined *portative* and attractive powers will be much *less* than the *sum* of their powers when acting *separately*. Thus two magnets, each of which separately is capable of supporting a weight of six pounds, will, when combined, possibly not be able to support a weight of more than, say, eight pounds.

But though magnets thus placed acquire jointly an increased attractive power, they, by induction, tend to *injure* each other by mutually *weakening* each other's magnetism. Thus the *north* pole of the one tends to induce the *south* pole in place of the *north* pole of the *adjacent* magnet. Where the north pole of the adjacent magnet is much weaker than its neighbour, the latter north pole may overpower the former, and actually convert, by induction, the *weaker north* into a *south* pole.

The *polarity* of a more *powerful* magnet may thus overpower and *reverse* the polarity of a *weaker* magnet.

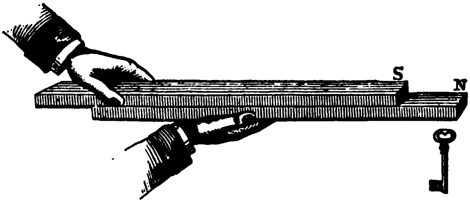

Fig. 28.—Showing the mutual action of two *dis*-similar poles in lessening the PORTATIVE and ATTRACTIVE powers of magnets.

49. *Case* 2. If the two bar magnets be placed side by side, as in the last case, but with their poles *reversed*, so that the *north* pole of the one magnet shall lie on the *south* pole of the other, also the *south* pole of the former on the *north* pole of the latter, as in fig. 28, their joint *portative* and *attractive* powers may be so greatly *reduced* as almost to *disappear*. But though their joint *portative* power is thus so greatly *reduced*, they, by induction, tend to *strengthen* each other, since each pole in the one magnet tends to *induce* its *opposite polarity* in its neighbour.

EXPERIMENT.—Take a bar magnet and suspend from its farther end a small key or piece of soft iron; then gradually slide on to it (as shown in fig. 28) a second bar magnet, of the same size and power of the first, but with its poles reversed. As the end of the second magnet approaches the opposite pole of the first, the attraction of the latter for the key will be gradually weakened, until the key falls off as though the magnet had lost its power. On removing the *upper* magnet the portative power of the *lower* one will be immediately restored.

50. The Attractive and Repulsive Powers of the Poles are the Resultants of the Attractive and Repulsive Powers of the Molecules of the Magnet.—The magnetic forces of the magnet do not, as *apparently* seems the case, *reside* in the *poles*, but are disseminated through the entire magnet, being *inseparable* from its constituent *molecules*. This apparent contradiction is explained by the following diagram:—Let A′A, BB′, fig. 29, represent a single row of the constituent molecules of a magnet. It will be seen that the *opposite* but *adjacent* magnetic fluids tend to *neutralise* each other's influence through the *general mass* of the magnet. This action, however, cannot apply to the *terminal* molecules, whose respective fluids cannot so neutralise each other, and which therefore *manifest* their respective polarities.

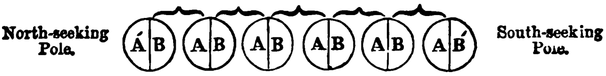

Fig. 29.—SHOWING AN IMAGINARY LINE OF MOLECULES IN A MAGNET. A, B, The *north* and *south* magnetic fluids of adjacent molecules, which tend to neutralise each other. A′, B′, The *north* and *south* magnetic fluids of the terminal molecules which manifest *polarity*.

The polarity of a magnet as a whole, that is, the existence of the *poles*, or the apparent accumulation of magnetic forces or fluids near the ends of the magnet, is thus the *resultant* of the action of the magnetic fluids of its *constituent* molecules.

51. Measurement of Magnetic Force.—The relative strength of two or more magnets may be determined by the following method:—

1. By determining their relative *portative power;* that is, by determining the weight which one magnet will sustain, as compared with its weight, in comparison with the weight which a second or *standard* magnet will support, as compared with its weight.

2. By the *method of oscillation.* A compass needle is really a magnetic pendulum, which, when disturbed, oscillates before again coming to rest, under the influence of magnetic force ; the greater the magnetic force, the greater the number of oscillations it performs in a given time. After deducting the effect of the earth's magnetism, the relative intensity of the powers of two magnets is as *squares of the numbers of the vibrations* performed by a compass needle, respectively under the influence of the two magnets, during a given time.

The student may readily convince himself of the general truth of the principle of this method by bringing a bar magnet near a compass needle in a state of *oscillation.* The nearer he brings the magnet to the *needle,* the more quickly it will oscillate; and, *vice versâ,* the farther he removes it, the more slowly the needle will move.

3. By determining the angles to which a given magnetised needle is repelled by the magnets to be compared. This operation is generally performed by means of an instrument termed the *torsion balance* (see Torsion Electrometer).

CHAPTER III.

TERRESTRIAL MAGNETISM.

52. The Earth Practically a Magnet.—The earth behaves very much as though it were a *magnet,* or rather as though it were a *spheroidal* mass having a comparatively short but powerful *bar magnet* lying *axially* in the direction of its magnetic poles, the *austral* magnetism of the bar predominating in the southern hemisphere, and its *boreal* magnetism predominating in the northern hemisphere. Such a magnet would make an angle of about 20° with the terrestrial axis, that is, the earth's *axis* of *rotation.* The general *magnetic phenomena* of the earth may be approximately imitated by means of a wooden globe containing a *bar magnet* mounted in the direction of its *axis*, its *north-seeking* or *marked* pole corresponding with the *south* magnetic pole of the earth, and its *south-seeking* with the *north* magnetic terrestrial pole.

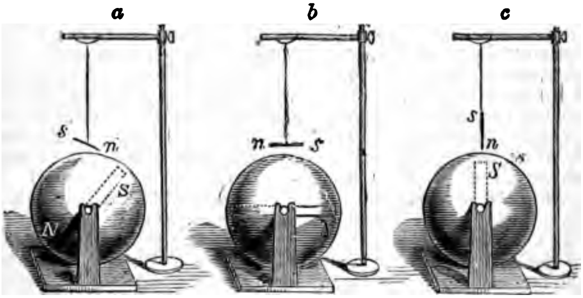

Fig. 30.—Wooden Globe with Bar Magnet (dotted lines) in interior, and compass needle suspended by thread from above. *a*, Dip in England; *b*, *no dip* at magnetic equator; *c*, dip at north magnetic pole.

Let *a b c*, fig. 30, represent a wooden globe, say twelve inches in diameter, having such a magnet in its interior, mounted *axially*, as just described.

Experiment I.—Over such a globe suspend a small magnetic (compass) needle by means of a thread, so that it may be supported immediately over the globe in such a position that its two ends shall be equally distant from the two opposite poles of the internal bar magnet. The compass needle will now assume a *horizontal* position, or position of *no dip* (as shown by *b*), imitating the behaviour of the ordinary compass needle at the earth's *magnetic equator*, or line of no dip.

Experiment II.—Hold such suspended compass needle over the globe, as shown in fig. *a*, so that it shall be supported over a position on the wooden globe corresponding to the position which London occupies on the earth's surface. The *north-seeking* end of the compass needle will now *dip* as in London.

Experiment III.—Hold such compass needle over a point in the surface of the wooden globe corresponding with that of the earth's north magnetic pole, as shown in fig. *c*. The needle will now *dip* vertically, its *north-seeking* end pointing *downwards*.

If these experiments be repeated with the opposite side of the wooden globe—viz., that which contains the *north-seeking* pole, and on which the *austral* magnetism predominates, similar effects will be produced, but the direction of the needle will be *reversed;* that is, its *south-seeking* end will now be attracted towards the globe, and therefore point *downwards*. (See also Art. on Ampèrian currents.)

53. Magnetic Elements.—A knowledge of terrestrial magnetism implies a knowledge of—(1) *Declination* (see Art. 54); (2) *Inclination* (see Art. 67); (3) *Intensity* (see Art. 71). These are therefore described as the *territorial magnetic elements*, or, more briefly, the *magnetic elements* of the place at which they are observed.

54. Magnetic Declination, nautically termed Variation, is the *horizontal* angle contained between the plane of the *true* or *geographical* meridian, and the plane of the *magnetic* meridian.

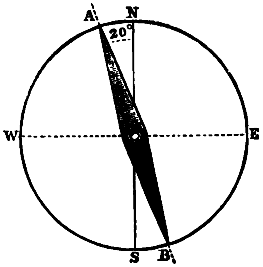

Fig. 31. — Compass Needle, showing Declination of 20° W.

The *plane* of the *terrestrial* or *geographical meridian* is the plane or flat surface which passes (*a*) through the observer at the place; (*b*) through the centre of the earth; (*c*) through the *north* and *south terrestrial* poles.

The *plane* of the *magnetic meridian* is the plane or flat surface which passes (*a*) through the centre of suspension of the compass needle in the vicinity of the observer; (*b*) through the centre of the earth; (*c*) through the horizonal axis, or the straight line passing through the points of the compass needle in its true position of *rest*.

Imagine a plane surface to pass through the *geographical* meridian of a given place; also imagine a huge plane surface to pass through the centre of suspension, and the two ends of a compass needle in the same place; the angle included between these *imaginary* plane surfaces is termed the *declination* at *that* place. The declination, therefore, *varies* at *different* places on the earth's surface.

At the present time, the declination at London is about 20° W.; that is, the magnetic needle (compass) points about 20° to the *west* of the true *north.*

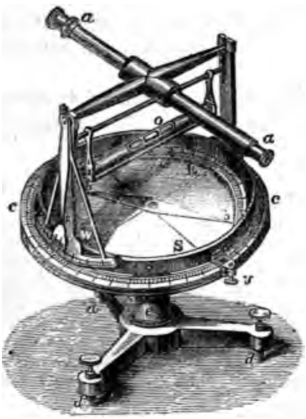

Fig. 32. — DECLINATION COMPASS. *a, a,* Telescope; *b, b,* compass box and needle; *c, c,* horizontal limb (graduated); *d, d, d,* tripod with levelling screws; *e,* pillar in which graduated limb rotates.

55. The Declination Theodolite, or Declinometer, or Declination Compass, is used to take the *declination* of a place. It consists essentially of — (*a*) A *telescope* mounted on a *horizontal axis* (and therefore capable of moving in a *vertical* plane). (*b*) A *compass box* (including light magnetic needle), to the sides of which two uprights are screwed, which give support to the telescope; the compass is mounted on a *vertical* axis, on which it rotates horizontally, carrying round with it a *vernier v,* for more accurate measurements. (*c*) A fixed *horizontal* limb (*azimuthal circle* graduated round its circumference) mounted on a tripod stand (*d*), which supports a *vertical* pillar (*e*), and is adjusted by three levelling screws, with the aid of the spirit level *o* attached to the telescope.

To Use the Instrument—(1) *Level* the *horizontal circle* and *compass* by means of the *tripod screws*. This result is accomplished when the bubble remains in the centre of the spirit level during the entire rotation of the *horizontal* circle. (2) Bring the telescope into the plane of the *geographical meridian, as* by turning it horizontally until its optical axis coincides with the centre of the sun at mid-day (that is, when the sun is at its greatest *altitude*). The *degree* of the *declination* may now be read off with great accuracy on the divided circle by means of the *vernier*. The compass needle will show whether the declination be *east* or west.

56. To Draw a Straight Line Pointing True North and South.—Place a *compass needle*, freely supported, on the table; allow the needle to come to rest; draw a straight line passing through the *centre* of suspension of the needle, and through a point in the compass card about 20° to the *east* of the straight line passing through the ends of the compass needle. Such line will, at London or Greenwich, point true *north* and *south*.

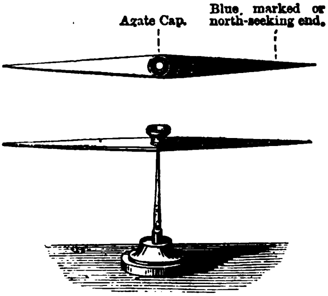

Fig. 33.—Magnetised Compass Needle Mounted on vertical steel point.

57. The Mariner's or Ship's Compass, used for the purposes of guiding the ship during its course of navigation, consists of the following essential parts:—

(1.) *A thin flat magnet* (the compass needle) mounted and supported horizontally on a sharp point or pivot, by means of a central cap of agate.

(2.) *A compass card* of printed paper or card, fastened to and *above* the *needle*, and floating with but concealing it, the *north* and *south* points of the compass *card* being fixed immediately *over* the *north* and *south* poles of the compass *needle*.

(3.) *A perpendicular pivot,* consisting usually of a *fine* point of steel properly hardened and tempered. In the Royal Navy pivots of *iridium*, which are hard and do not *rust* or oxidize, are used.

(4.) *A shallow* brass or copper *box a*, with glass cover which encloses and protects the compass needle and card.

(5.) *Two gimbals*, or concentric rings or hoops, into the inner one of which the compass box itself is loosely fixed by two pivots *e*, placed axially at opposite points in the ring. The *inner* ring is similarly fixed (so as to permit of its free movement) into the *outer* ring, or three-quarter ring, out with its *pivots f* and *g* at right angles to those of the compass and inner ring. By this arrangement, however much and in whatever way the ship may roll, the *horizontality* of the compass is preserved. This arrangement is very similar to that by which the cabin lamps are mounted on board steam-vessels, and which is familiar to most summer excursionists.

The whole is generally mounted in an outer wooden box or case *d*, *m*, *h*. Great care is requisite to ensure the *absence* of iron or steel in the construction of the case and surrounding fittings.

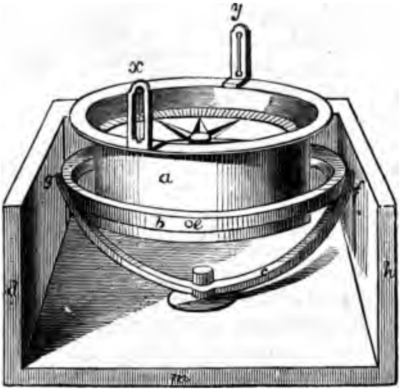

Fig. 34. — MARINER'S COMPASS. *a*, Compass box containing compass needle and floating card; *b*, *c*, gimbals; *d*, *h*, *m*, external wooden case; *e*, one of the pivots on which compass case swings; *f*, *g*, pivots on which horizontal *gimbal* swings; *x*, *y*, *sight vanes* sometimes attached to magnetic compasses, especially *land compasses.*

Magnetic compasses are sometimes fitted with *sight vanes*, *x* and *y*, for the purpose of measuring *horizontal* angles, or for determining the *magnetic azimuth.*

58. The Compass Card consists of a circular disc (see fig. 34), the *outer* edge or circumference of which is frequently graduated into 360 degrees, on the interior of which is printed a *star*, the radiations of which divide it in thirty-two points, termed *rhumbs*, or *points of the compass.* The point indicating the *north* (which is fixed immediately over the *north* end of the compass needle) is frequently distinguished by the figure of a royal crown.

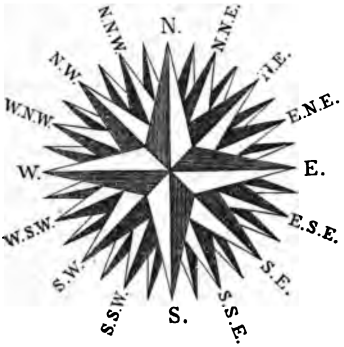

Fig. 35.—Compass Card, showing the 32 points of the Compass.

59. The Land Compass differs from the *marine* compass chiefly in the arrangement of the *needle* and *card.* The needle is either suspended *above* the card, its *marked* end indicating the degree of *horizontal* deviation from the magnetic meridian by means of the scale printed round the edge of the flat card, or is suspended *within* a *brass ring* graduated into degrees. The land compass is also in general fitted with a small *stop* or *lever* to raise the needle from its bearings when not in use, or to bring it more speedily to rest during its use when taking observations.

When fitted with a *reflecting prism* and a *sight vane* (x, y, fig. 34), it forms the *prismatic* or *azimuth compass,* a most valuable instrument to the military surveyor; also for filling in the details of an extensive survey.

To use the instrument, hold it horizontally in such a position that, in looking through the *slit*, the *thread* of *sight vane* and the object shall be in the same right line, and the number of the degree on the floating compass card, which coincides with the thread of the *sight vane*, will show the *magnetic azimuth* or *angle* which a straight line drawn from the object to the eye makes with the *magnetic meridian.*

60. The Earth's Action on the Compass Needle is simply Directive, and not Attractive.

EXPERIMENT.—Mount a small compass needle so that it may move freely on a pointed wire projecting perpendicularly from the middle of a large, round, flat cork. Place the cork gently in the middle of a tub or basin filled with water.

The mounted compass needle will remain where it was originally placed, in the centre of the basin, showing no tendency to pull the cork to one side or the other. But the *needle* will place itself in the *plane* of the *magnetic meridian*, that is, unless interfered with by some external agent, it will come to rest so that its opposite ends point respectively in the direction of the *north* and *south magnetic poles.*

Thus the compass needle *as a whole* is not *attracted* or *repelled* by the earth's magnetism, or it would be *pulled* or *driven* to one side or the other of the basin. But the earth's magnetism *directs* it as to the way it shall point, or, in other words, determines the *direction* of its position of *rest.*

This result is brought about as follows:—(*a*) The *north terrestrial* (boreal) magnetic pole *attracts* the *north-seeking* (austral) pole of the needle, and repels its *south-seeking* (boreal) pole. (*b*) The *south terrestrial* pole (austral) *attracts* the *south-seeking* (boreal) pole of the compass needle, and *repels* its *north-seeking* (austral) pole. (*c*) The distance between the *terrestrial* poles and each of the poles of the compass needle being *practically* equal, the *attraction* and *repulsion* exercised by the terrestrial poles are also practically equal, therefore the compass needle undergoes no motion of *translation*, but is, when placed *obliquely* with the magnetic meridian, pulled round, performing a sort of *rotatory* movement until it has placed itself in the plane of the magnetic meridian. The compass needle having taken up this position, the two equal and opposite terrestrial polar forces, acting from directly opposite points tend to keep it in a state of rest. The magnetic action of the earth is thus *directive*, and not *translatory*. If the *length* of the compass needle formed any important fractional part of the distance of the needle from the earth's magnetic pole, the *repulsion* of the latter would be so much *less* for the one end than its *attraction* for the other, that the needle would then be *attracted* to it by a *resultant* force of *attraction* equal to the *difference* between the forces of attraction and repulsion exerted on the needle.

61.* Secular Variations.—The compass needle, however, does not permanently retain the same *declination* even at the same place; but undergoes a *gradual* change, now to the west and then to the east, passing each year through more or less a cycle of change which occupies an indefinite time, it may be several centuries, in its completion. To these *variations* of *declination*, which take centuries to accomplish, and the *duration* of which are unknown, the term *secular variation* is applied.

In 1580, the declination was 11° 15′ E.; in 1657 there was *no declination* in London, that is, during that year the compass needle pointed true *north* and *south;* from that date till 1815, when it attained its *maximum* of 24° 27′ W., it gradually increased to the west. Since then the needle has been gradually turning towards the east, its declination in London being, as previously stated, about 20° W., its *annual* decrease being apparently about 7′.

62.* Annual Variations.—In addition to its *secular* variations, the compass needle undergoes other comparatively trifling and less marked variations, more especially about the time of the *equinoxes*, which are termed *annual* variations.

63.* Diurnal Variations.—In addition to both its *secular* and *annual* variations, the compass needle, as was first observed in 1724 by Mr. Graham, also undergoes *diurnal* or daily variations, the *north-seeking* end of the needle in this hemisphere travelling perceptibly to the west from 8 A.M. to 1 P.M., and during other parts of the day in the contrary direction. Careful observation of facts connected with *annual* and *diurnal* variation, would seem to show that the sun's *heat* exerts its influence on terrestrial magnetism, the magnetism of the earth probably depending at least in part on its *thermo-electric currents*, more or less excited by the *solar* rays.

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* The student need not attend to the paragraphs marked* on the first reading of this little book. For fuller information on *Magnetism and Electricity*, see Advanced Course, in this series.

64. Magnetic Perturbations or Storms.—*Irregular* or *accidental* variations of *declination* or *inclination* are termed magnetic storms. They almost always accompany strongly marked displays of the *aurora borealis*, great *earthquakes*, and very violent *volcanic eruptions*. On such occasions, the needles employed in telegraphy sometimes move *spontaneously*, and at others refuse to transmit the ordinary signals.

The student must not, as is not unfrequently the case with popular readers, be misled by the term *storm*, to suppose that during such phenomena the needle necessarily takes to rapidly oscillating backwards and forwards. On the contrary, on such occasions it sometimes becomes unusually fixed and stationary, but to the east or to the west of its *normal* or *mean* position. Such perturbations, according to Humboldt, who first drew attention to them, frequently manifest themselves over hundreds and thousands of miles simultaneously. Professor Balfour Stewart has made a number of observations, showing the connection of *sun spots* and *magnetic storms;* these storms occurring most frequently, at intervals of ten or eleven years, on the occasions when the spots on the face of the sun are also most numerous.

65.* Agonic Line.—The agonic line is the imaginary, irregular, curved line supposed to be drawn on the earth's surface, so as to connect all those places which have *no declination*, that is, at which the *compass needle* points true *north* and *south*, and at which, therefore, the *magnetic* and *geographical* meridians *coincide*. The *agonic* line is therefore the *line of no variation*.

66.* Isogonic Lines are the imaginary irregular curved lines on the earth's surface which connect places having *equal* declination.

67. Inclination or Dip is the *angle* which a freely suspended *vertical* magnetic needle, supported by and *moving* on a *horizontal* axis, makes with the *horizon* when the *vertical* plane in the needle *coincides* with the *magnetic meridian.*

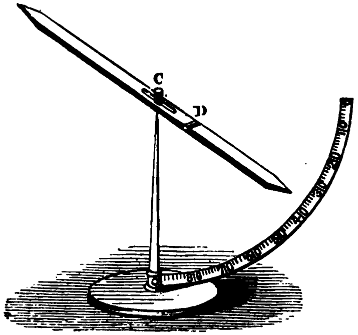


Fig. 36.—SIMPLE FORM OF DIPPING NEEDLE. C, Agate cap; D, north or *dipping* end of Needle.

The *dip* in London, at the present time, is about 67°. At the magnetic *poles, north* or *south,* the *dipping* needle would become quite *vertical,* while at the magnetic *equator* it would come to rest in the *horizontal* position.

The straight line passing through the points of the dipping needle, when in its normal position, is termed *the line of force.*

68. The Dipping Needle or Inclination Compass, is used to determine *inclination* of a place. The more elaborate forms of the instrument, such, for instance, as are suitable for scientific research (see fig. 37) consist of—

(*a.*) A *vertical* magnetic needle of great accuracy of adjustment, supported by means of a *horizontal* axis, on highly polished surfaces of *agate,* in the centre of the divided circle.

(*b.*) A vertical graduated circle of brass, capable of *horizontal rotation.*

(*c.*) A *stage* and framework of brass supporting the *vertical* circle and needle attached below to a *vertical axis,* capable of horizontal rotation in the vertical tubular fitting attached to the tripod.

(*d.*) A *lower* horizontal graduated circle fixed to, but *movable* on the hollow axis attached to the tripod.

(*e.*) A *spirit level* fixed to rotating stage (*c*).
Three *levelling* screws working in tripod (*s*, *s*, *s*).

The *upper* part of the instrument is usually covered with a glass case.

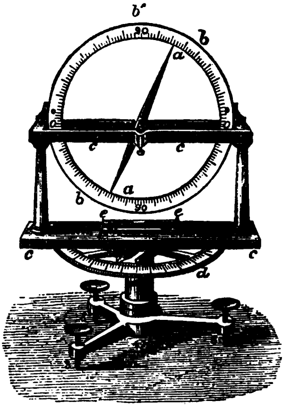


Fig. 37.—DIPPING NEEDLE.

To Use the Instrument.—(1.) *Level* the instrument by turning the *tripod screws* until the *air bubble* remains in the *middle* of the *spirit level*. (2.) Bring the vertical needle to such a position that it can *oscillate* or *rotate* in the plane of the magnetic meridian only as follows:—Turn the *stage* (*c*) and vertical circle (*b*) until the needle comes to *rest* in a *vertical* position (*b′*) in the figure. Now turn the *stage* and *upper* circle round 90° as measured on the *lower* circle. The needle will now oscillate in the *magnetic* meridian. (3.) Observe the angle at which the magnetic needle now stands, as measured on the vertical circle, and this will be the *inclination* of the place at which the observation is made.

69.* The Aclinic Line or Magnetic Equator, is the imaginary, irregular, curved line which is supposed to pass through those points in the earth's surface at which the *dipping* needle has no *dip*, that is, remains (in its position of rest) parallel to the *horizon*. The *aclinic* line (*a*, *b*, c, *d*) therefore the *line of no dip*. It cuts the geographical equator in several points.

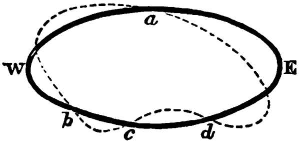


Fig. 38.—GEOGRAPHICAL AND MAGNETIC EQUATOR

70.* The Isoclinic Lines are the imaginary, irregular, curved lines which join places on the earth of *equal dip;* they are therefore *lines of equal dip.*

71. Intensity or **Magnetic Intensity** is the amount or degree of the earth's magnetic force, by which a magnetic needle of unit *size* and *strength* is brought back to its position of *rest,* when moved a given distance from that position, supposing such needle to be *freely* suspended about its *centre of gravity,* so as to be capable of moving equally in any direction.

The relative intensity of the earth's magnetism, at any two places, may be ascertained by counting the number of times the needle oscillates in a *given time* at the two places, on being put out of its position of rest. The relative magnetic intensities, at the two places, will be as the *squares* of numbers of the oscillation at the two places. Thus, if the needle oscillated five times at the one place, whereas it oscillated seven times at the second place, the relative magnetic intensity at the two places will be as $5^2=25$ to $7^2=49$; that is, at the second place, the magnetic intensity would be practically twice that of the first.

72. The Magnetic Poles are those points in the earth's surface at which the *dipping needle,* in its position of *rest,* its *plane of oscillation* being in the magnetic meridian, stands *vertical,* or makes an angle of 90° with the *horizon.*

Possibly there are *two* magnetic poles of unequal power in *each* hemisphere.

If a *dipping needle* were carefully removed from one magnetic pole to the other, say from the *north* to the *south* magnetic pole, the needle would pass from its positive perpendicularity at the north pole, through every degree of obliquity (its north pole rising and its south pole falling), until at the *magnetic* equator it will have become *horizontal,* having on its passage slowly described an angle of 90°. On being removed from the *magnetic equator* to the south magnetic pole, it would pursue an opposite course, gradually passing from its *horizontal* position at the *equator,* to a *vertical* position at the south terrestrial pole, *its* south pole still falling, and its north pole rising as before. until it again assumed a *vertical* position.

CHAPTER IV.

HISTORY OF FRICTIONAL ELECTRICITY.

73. **Thales** of Miletus, B.C. 600, is said to have been the *first* philosopher who discovered the *electrical* power of *rubbed amber.* Later on, **Theophrastus**, B.C. 32, and Pliny, A.D. 70, mention its power of *attracting* dry leaves and straws. They also mention a mineral, supposed to be *tourmaline,* as possessing similar properties. **Pliny** and **Aristotle** described the *electrical* powers of the *torpedo.* A case of *gout* cured by the shocks of a *torpedo* is likewise mentioned, as also cases of the emission of electrical *sparks* by the human body.

Eustathius, A.D. 415, records a case in which the body of a philosopher occasionally, while dressing and undressing, *cracked* and emitted sparks and flame, which did not burn his clothes. No *theory* or *explanation* of these phenomena worthy of the name of science was attempted till the time of **Dr. Gilbert** of Colchester, A.D. 1600, who, by a series of very elaborate experiments, very greatly extended the number of bodies known to possess the properties of *amber;* he also made experiments with the object of determining the influence of the *atmosphere* on the *electrical condition* of bodies.

74. After this **Boyle**, A.D. 1675, made a series of experiments with the view of determining the *origin* of electricity, in which he greatly extended the discoveries begun by Dr. Gilbert. Boyle first used the *resinous cake* as a *source* of electricity.

Otto Guericke (who was contemporary with Boyle) about this time invented what may, perhaps, fairly be described as the *first electrical machine,* which consisted of a *globe* of *sulphur* made to revolve on an axis, so as to be excited by the *friction* of the *hand* applied to its surface. He thus showed that *light* and *sound* were always produced when the electrical excitation was sufficiently powerful.

75. Sir Isaac Newton probably constructed the first *glass* electrical machine. His experiments were *repeated* by the Royal Society on the 13th of January, 1676, a *scrubbing brush* of short *hog's bristles* being used to excite the *glass*. **Francis Hawksbee,** about 1705, was the first to observe the resemblance between the *electric spark* and lightning. About this time **Stephen Gray,** a Fellow of the Royal Society, made an extensive and important series of experiments on electrical *excitation, conduction,* and *attraction.* Nearly cotemporaneously (about 1733), **M. Dufay,** of the Academy of Science (Paris), made the still more important discovery of existence of *two dissimilar* kinds of electricity, to which he applied the distinctive titles of *vitreous* and *resinous* electricity, thus inventing the theory generally known as "Dufay's theory." Shortly after this date, Professor Boze, of Wittemberg, added the *prime conductor* to the electrical machine of Sir Isaac Newton.

Between 1744–46, the **Leyden Jar** was discovered, for the more minute history of which see Art. on Leyden jar. Shortly after this, Sir W. Watson imaged out the "*plus* and *minus* electricity" theory, afterwards more carefully and thoroughly worked out by Dr. Franklin. Between 1747 and 1760, the science of electricity made great strides, chiefly through the labours of **Dr. Franklin,** who not only worked out the *plus* and *minus* or *positive* and *negative* theory of electricity, but among other important discoveries proved the *identity* of *electricity* and *lightning,* and invented *lightning conductors.* About the latter portion of this period,

76. Mr. Symmer accidentally found that when a *black* and a *white silk* stocking were put on the same leg, and taken off at the end of about ten minutes, they were so much inflated or distended when pulled asunder, that "each of them showed the entire shape of the leg, and at the distance of a foot and a half they rushed to meet each other." Led by the interest thus excited, he entered on a series of experiments on which he founded the theory most generally adopted at the present day, and known as **Symmer's theory**, and in which he adopted *Dufay's double-fluid* theory of electricity, combined with the nomenclature (the *positive* and *negative* fluids) of the *Franklinian* theory. From this period down to the present, the number of the labourers, including those of Epinus, Cavendish, Coulomb, Laplace, Lavoisier, Volta, Saussure, Biot, Arago, Sir H. Davy, Daniell, Faraday, Harris, Tyndall, and others of eminence, is so great, and their discoveries so interwoven with the present state of electrical knowledge, as to place them beyond the limits of our present space.

CHAPTER V.

FRICTIONAL (STATICAL) ELECTRICITY, ATTRACTION, REPULSION, CONDUCTION.

77. **Electricity** (from Gr. *elektron*, amber) is the *imponderable* physical agent, *cause*, force, or the *molecular movement*, by which, under certain conditions, certain *phenomena*, chiefly those of *attraction* and *repulsion* (and where the force exists in great quantity or intensity, of heat, light, sound, magnetism, and chemical action) are produced.

It owes its name to its power of *attraction*, having been first observed in connection with *rubbed amber* by Thales of Miletus, who accidentally discovered that if a piece of *amber* was *rubbed* by the hand, it acquired the property of first *attracting* and then supporting minute light bodies which temporarily *adhered* to its surface. The exercise of this power was, after the fashion of those days, attributed to the *spirit* or *soul* of the amber.

78. Sources and Kinds of Electricity.—Electricity may be excited or developed by various means, chiefly friction and mechanical action, chemical action, heat, and magnetism. When developed by *friction*, compression, concussion, or disruption, it is termed *frictional* or *statical* electricity; when by heat, *thermo-electricity;* when developed by chemical action, *voltaic* or galvanic electricity; and when by magnetism, *magneto-electricity.* These differently named electricities are all essentially of the same kind or nature, differing among themselves chiefly in relation of *quantity* and *intensity.*

79. Statical Electricity (from Gr. *statos*, standing) is in general developed by *friction.* It is so named because it tends to *remain*, or, as it were, *stand* where it is developed, or to distribute itself over the *surface* of bodies and there come to *rest.*

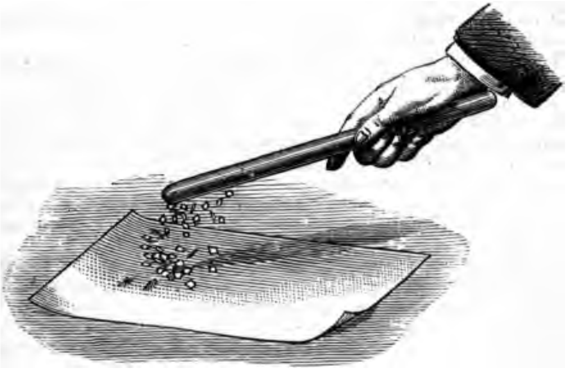


Fig. 39.—SHOWING ATTRACTION AND REPULSION OF LIGHT BODIES, as feathers (down), chopped straw or paper, bran, sawdust, gold-leaf, and pith balls, by warm *rubbed* rod of vulcanite, sealing-wax, or glass.

80. Phenomena of Attraction and Repulsion.—ALL bodies when *rubbed* acquire the power of *electric attraction* and *repulsion.* Certain bodies, therefore formerly termed *electrics*, manifest this power with great facility under ordinary circumstances; other bodies, not manifesting this power, because the necessary conditions were then unknown to the experimentalists, were erroneously termed *non-electrics*.

Experiment I.—Rub a piece of amber, a *vulcanite* ruler, a *glass* tube, a stick of sealing-wax, or sulphur on the sleeve of the coat, or with a piece of warm dry flannel or silk, and then bring the *rubbed part* near to a collection of very small scraps of paper, sawdust, bran, cut straw, small pith balls, or other *light* bodies, as shown in fig. 39. These bodies will be immediately *attracted* to the *rubbed substance*, some of them *adhering* to it, while others will assume a lively movement, being alternately *attracted* to or *repelled* from it, the light bodies rapidly oscillating, as it were, between the *rubbed substance* and the *table* or support. If amber be used, it is better to rub it with flannel.

Experiment II.—Hold the *rubbed body* very near the face. A peculiar sensation, much as though the face were covered with adhering *cobwebs*, will be produced.

Experiment III.—If the *rubbed body* be a *large* one, hold it to one of the knuckles—a feeble *spark*, accompanied by a slight *crackling*, will be produced.

Experiment IV.—(*a*) Take a piece of thick *brown paper* about 12 inches square; (*b*) heat it before the fire, and when hot *rub* it with a common clothes brush; (*c*) hold it over a collection of light bodies as in Ex. I., they will be immediately *attracted* as before; (*d*) hold the hot, *rubbed* paper over the *hair* of the head, it will be immediately attracted, many of the hairs "standing straight on end," and presenting a very peculiar appearance; (*e*) hold the hot, freshly-*rubbed* paper near the wall of the room, it will immediately fly to and cling to the wall; (*f*) *sparks* may sometimes be drawn by the knuckle from the paper.

Experiment V.—Repeat the last experiment before the fire by drawing the *hot brown paper* two or three times between the knees of your trousers, similar effects of attraction will be produced. This is an amusing class experiment with boys.

Experiment VI.—Repeat the experiment with warmed foreign post paper, *rubbed* with bottle india-rubber; similar phenomena will be produced.

Experiments VII.-X.—Repeat the above experiments with

(7.) *Silk ribbon*, rubbed with *vulcanized india-rubber*.

(8.) *Collodion*, rubbed with the *fingers*.

(9.) *Glass tube*, rubbed with silk on which *amalgam* has been spread.

(10.) *Resin*, rubbed with *flannel*.

Experiment XI.—Balance a wooden lath, 2 or 3 feet in length, on a Florence flask, as shown in fig. 40. On bringing a *rubbed* stick of vulcanite or of glass near the end of the mounted rod, it will be *attracted* by it, and may be made to *rotate* on the flask by gently moving the excited rod before it.

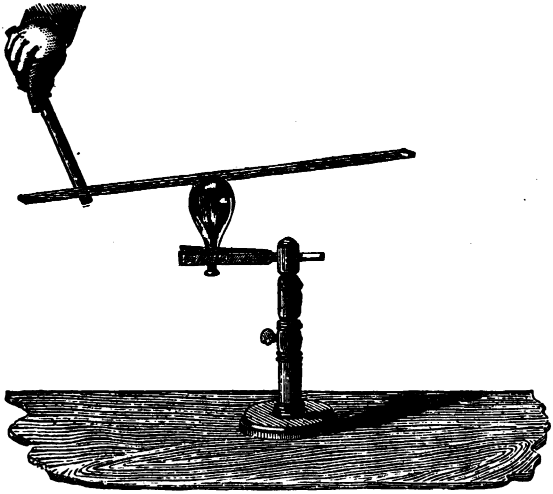


Fig. 40.—SHOWING ATTRACTION OF A WOODEN LATH by a rod of excited vulcanite.

EXPERIMENT XII.—Bring an excited glass or vulcanite rod successively near each end of a mounted compass needle (fig. 33), it will, as in the case of the mounted lath in the last experiment, *attract* both ends without any distinction of *polarity.*

The student, with the exercise of a little ingenuity, may multiply these experiments indefinitely, in all cases similar effects of *attraction* will be produced. He should also repeat the above experiments with the aid of an *electric pendulum,* and a gold-leaf electroscope (see Arts. 82 and 111).

81. Electrified Body.—The *rubbed body* thus capable of giving rise to the phenomena of attraction, repulsion, etc., just described, is said to be *electrified, electrically excited,* or *charged* with electricity.

The *Act of Electrification by Friction*, as defined by Tyndall, "consists in the forcible *separation* of the two electric fluids, one of which is diffused over the *rubber*, and the other over the *body rubbed.*

The *force* by which the two fluids are thus separated, and tend to move in opposite directions, is termed the *Electro-motive force.*

82. The Electric Pendulum or Pith-ball Electroscope is a form of instrument frequently used when it is desired to conduct these experiments more carefully. It consists of (see fig. 41):—

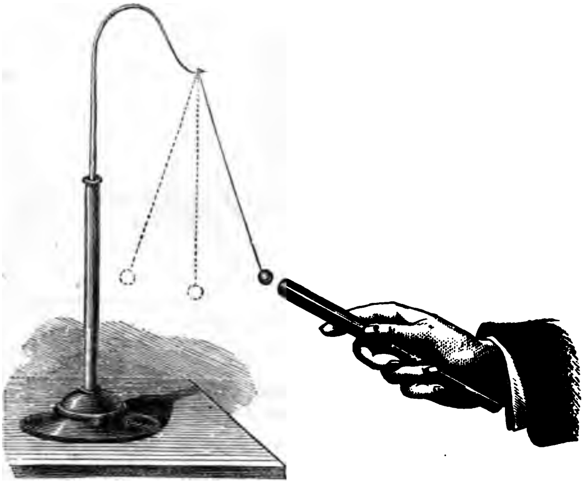


Fig. 41.—THE ELECTRIC PENDULUM OR PITH-BALL ELECTROSCOPE. The *middle* ball shows the original position of the *un*electrified pith ball—the shaded ball to the *right* shows its position under the *attractive* influence of the *rubbed* vulcanite or glass rod; the dotted ball to the *left* its position during *repulsion* after having *robbed* the vulcanite of part of its electricity.

(1.) A *pith ball*, suspended by a fibre of *unspun* silk or other *insulating* material.

(2.) A stand for same, consisting in general of a pillar of glass, vulcanite, or gutta-percha, with suitable base, the whole supporting a bent arm, to which the silk fibre is attached. The *gold-leaf electroscope* forms a still more delicate instrument for investigating these phenomena (see Arts. 54 and 109–112.)

83. Two Kinds of Electricity.—The following experiments tend to prove the existence of two kinds of electricity.

EXPERIMENT I.—(*a*) Rub a stick of *sealing-wax* or a lump of *resin* with warm *flannel;* (*b*) bring the *sealing-wax* near the *pith ball.*

1. It will be *attracted* to the *sealing-wax* and become *charged* by contact with a part of its *electricity.*

2. *After contact* it will be *repelled* by the sealing-wax, thus showing that bodies charged with the same kind of electricity *repel* each other.

EXPERIMENT II.—(*a.*) Rub a *glass* rod or tube with a piece of *warm silk.* The effect is increased if the silk be covered with a little *amalgam.*

(*b.*) Bring the excited *glass* tube near the *pith ball.* It will be attracted (as in the last experiment with the sealing-wax) into contact with the *glass,* thus becoming charged with a portion of its electricity.

(*c.*) *After contact* the *pith ball* will be *repelled* by the *electricity* of the *glass,* thus again proving that bodies charged with the *same* kinds of electricity *repel* each other. In this case the *repelling* electricity is termed *positive* electricity.

EXPERIMENT III.—(*a.*) Rub a stick of *sealing-wax* or a piece of *resin* with warm *flannel.*

(*b.*) Rub a *glass* rod or tube with a piece of warm *silk.*

(*c.*) *First* bring the *sealing-wax* into *contact* with the *pith ball.* *After contact* the pith ball will be *repelled,* because of its having become charged with *similar* electricity to that of the sealing-wax.

(*d.*) Now quickly remove the *rubbed sealing-wax,* and in place of it bring the *rubbed glass* towards the *pith ball.* The *pith ball* will immediately *fly* to the *rubbed glass.*

EXPERIMENT IV.—(*a.*) Excite a piece of *silk* ribbon by rubbing it with *vulcanized india-rubber* as previously described.

(*b.*) Bring the two halves of the electrically-excited ribbon near each other, they will immediately *repel* one another, being charged with *similar* electricity.

(*c.*) Bring either half of the ribbon near the vulcanized india-rubber and it will be *attracted* by it, the *ribbon* and the *rubber* being charged with *opposite* electricities.

EXPERIMENT V.—(*a.*) Rub a small sheet of thin foreign post paper (previously well warmed) with india-rubber.

(*b.*) Speedily cut the paper into narrow *strips*, collect the strips together, and they will *repel* each other, forming a kind of tassel in consequence of their being charged with the *same* kind of electricity.

(*c.*) Bring the strips near the *rubber* and they will be immediately *attracted*, because charged with *opposite* electricities.

These experiments prove the existence of *two kinds* of electricity, viz.:—(*a.*) That which is excited by rubbing *glass; (b)* that which is excited by rubbing *resin* or *sealing-wax.* They also prove that though these electricities are *self-repulsive*, they are mutually *attractive* of each other; that is, that *positive* electricity will repel *positive* electricity, and *negative* will repel *negative* electricity, but that the *positive* and *negative* electricities will mutually *attract* each other.

84. Vitreous (Positive) Electricity (from Latin *vitrum*, glass).—The term *vitreous* electricity was formerly applied to the electricity generated by rubbing *glass* with *silk.* But this term has long since been generally abandoned, since the same *kind* of electricity can be obtained by the *rubbing* of innumerable substances; further, what was formerly termed *resinous* electricity may also be obtained from glass by rubbing it with special bodies. The term *positive* is now generally used in place of *vitreous*, as applied to electricity.

85. Resinous (Negative) Electricity.—This term, which was formerly applied to that *kind* of electricity which is excited by rubbing *sealing-wax* (which consists chiefly of *resin* and *shell-lac)*, has also now been generally abandoned in favour of the term *negative* electricity, since it also may be obtained from innumerable sources.

86. Apparatus for Testing the Action of Rubbed and Unrubbed Bodies on each other.—The following simple form of apparatus for *suspending* bodies (see fig. 42) will be found very useful, in addition to the pith ball electroscope previously described, in testing the action of *rubbed* and *un*rubbed bodies on each other, especially when they assume the form of rods or tubes. It consists (1) of a piece of *paper* or *wire* bent in the form of a *stirrup*, on which the rod may be balanced, as shown in the figure; (2) an *insulating* support, consisting of fibres of *unspun* silk, fastened *below* by a knot to the top of the *stirrup*, and above by a similar knot, or by a small hook to a bent arm, or any other convenient support.

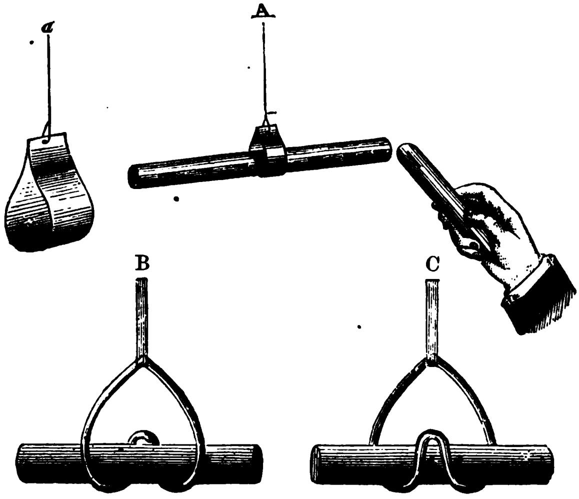


Fig. 42.—Mode of suspending Insulated Electrified Bodies. A, showing mode of testing the action of two *rubbed* rods of vulcanite; *a*, paper stirrup for suspending rod; B, front view of wire stirrup; C, back view of wire stirrup.

On a larger scale, as for lecture purposes, the wire or paper stirrup may be supported by means of *silk* tape, or ribbon.

Excited glass, vulcanite, and other rods and tubes, with polished slippery surfaces, may be *freely balanced* on metallic points, as shown in fig. 43. The process of balancing is greatly facilitated if the rod be centered experimentally by means of a puncture made in the middle of a lozenge-shaped piece of thick paper gummed on to the middle of the rod, as shown in upper figure of the diagram.

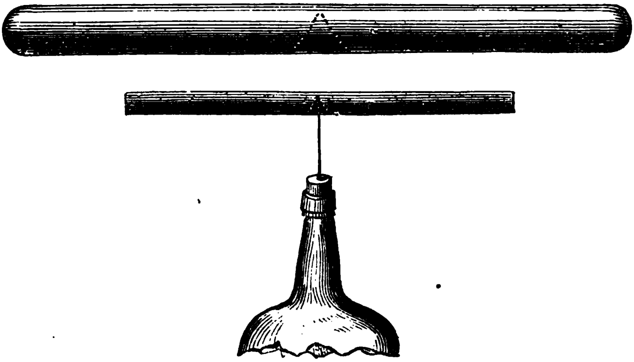


Fig. 43.—METHOD OF BALANCING INSULATED ELECTRIFIED RODS AND TUBES. Showing mode of freely balancing *rubbed* or *electrified* rods on metallic points passed through cork, and supported by common glass bottle.

For further hints ôn the construction of cheap apparatus, see Appendix.

87. Action of Rubbed Bodies on each other.—1. If rubbed with the *same* materials:—*Rubbed* bodies, as a rule, *repel rubbed* bodies of the *same* kind, when both are rubbed with the *same* material. Thus, one piece of *sealing-wax* rubbed with *flannel* will *repel* another piece of sealing-wax rubbed with flannel; and one piece of *glass* rubbed with *silk* will *repel* another piece of *glass* rubbed with silk.

2. If rubbed with *different* materials:—*Rubbed* bodies sometimes *attract* and sometimes *repel* rubbed bodies of the *same* kind when these bodies are rubbed with *different* materials; thus, a piece of *glass* rubbed with *silk* will *attract* a similar piece of *glass* rubbed with a piece of a *cat-skin;* and two pieces of glass, the one smooth the

other rough ground, so as to be semi-transparent, will, when rubbed together, *attract* each other.

88. Action of Rubbed on Unrubbed Bodies.—*Rubbed* bodies invariably *attract* *un*rubbed bodies when the latter are in their ordinary or *normal* state. They first decompose (by *induction*) the *neutral* electricity of the *un*rubbed body into its *positive* and *negative* electricities, and then *attract* them through the agency of the *nearer* electricity of that *un*rubbed body, which, under such circumstances, is always of the *opposite* kind to that of the *rubbed* body (see Induction).

89. Repulsion the only sure Test of the Presence of Free Electricity.—From the last Article it will be evident that electrical *repulsion* is the only sure test of the presence of *free* electricity, since not only *rubbed,* that is electrically charged, bodies *attract,* but *neutral* bodies also; whereas only electrically *charged* bodies can electrically *repel* each other. Thus *repulsion* is alike the only sure test both in Magnetism and Electricity (see Art. 7).

90. Electrics and Non-Electrics.—It was formerly supposed that a limited number of bodies only were capable of becoming *electrically excited* when rubbed. Bodies thus capable of becoming electrically excited, or of generating electricity, were termed *electrics,* in contradistinction to other bodies which were *not* found to be electrically *excited* after such *rubbing,* and which were therefore *supposed* to be incapable of generating electricity by *rubbing,* and were consequently termed *non-electrics.*

This distinction of bodies into *electrics* and *non*-electrics is now abandoned, since it is found that all bodies are *electrics,* that is, capable of becoming *electrically excited* when *rubbed.*

EXPERIMENT I.—(*a.*) Rub a glass tube with warm silk, and bring it near the pith ball of the electroscope (fig. 41); it will be first *attracted* and then *repelled.* Electricity has, therefore, been *generated* (liberated) by rubbing.

(*b.*) Rub a *brass* rod or tube with warm *silk*, and proceed as before. The *pith ball* will neither be *attracted* nor *repelled*, nor in any other way affected. Thus, *apparently*, no electricity was *generated* (liberated); *brass* was therefore formerly described as a *non-electric*.

(*c.*) Hold the *brass* or *metallic* rod or tube by means of a *warm dry glass* handle (see fig. 44), or by means of two or three layers of *vulcanized india-rubber*, and *rub* as in the last experiment; then bring it near the *pith ball* of the electroscope; it will now be *attracted* and *repelled* as in the first instance. The brass tube is evidently an *electric*.

(*d.*) Repeat the experiment as in the last case, but *before* bringing it to the *pith ball*, *touch* it with the *finger*, or with a *wire*, and then bring it to the pith ball, it no longer possesses its power of *attraction* and *repulsion*.

Fig. 44.—Apparatus for proving Metals to be Electrics. Consisting of glass rod (A), inserted as a handle into brass tube (B). To excite electrically, hold by warm glass handle, and strike quickly several times with dry warm *flannel*, or, still better, with cat's skin.

The student may afterwards repeat these experiments with advantage with the aid of a *gold-leaf electroscope*.

91. The *finger* or the *wire* in that last experiment has *conducted* its electricity to the ground; they are, therefore, termed *conductors* of electricity. The *glass* and the *vulcanite* possess no such power, or possess it only in so inferior a degree as to be unimportant; they are therefore termed *non-conductors*.

The so-called *electrics*, therefore, consist of bodies in which the electricity excited by *rubbing* is unable to escape (except very slowly), and therefore manifests itself in effects of *attraction* and *repulsion*, while, in the case of the so-called *non-electrics*, the electricity escapes, because of their superior *conducting* power (except under circumstances of peculiar precaution), with such rapidity that they have *not time* to manifest these effects.

Non-conductors were termed Dielectrics by Faraday, because of their permitting of the *inductive* action of *electrified* bodies being exerted *through* their substance on adjacent bodies placed on the *opposite* side of them.

92. Electrical Conductors are, therefore, bodies which possess the power of readily transmiting or conducting electricity from one body to another, or to the ground. All bodies offer some *resistance* to the *passage* of electricity; with some bodies this *resistance* is so *feeble* as to be almost *inappreciable;* they are, therefore, said to be *good conductors.* With other bodies the *resistance* offered is so great that practically *no* electricity passes; they are, therefore, termed *non-conductors.* Correctly speaking, however, all bodies, even the most *perfect* conductors, offer a certain amount of *resistance* to the *passage* of electricity; and all bodies, even the *worst* conductors, allow a small quantity of electricity to *pass.* Consequently, there is no such thing as an *absolute* conductor or *non-conductor;* that is, *conduction* and *non-conduction* are simply relative *degrees* of *conduction,* from which it follows that there is no *conductor,* however good, which, if its *length* were sufficiently increased, would not offer appreciable or even measurable resistance to the *passage* of electricity; and there is no *non-conductor* which, if it were sufficiently reduced in thickness, would not allow an appreciable quantity of electricity to *pass.*

EXPERIMENT.—Wipe an *excited* rod of *glass* or *vulcanite* with a damp cloth, or roll it up in a sheet of metal foil, it immediately loses its electrical properties, its *charge* being *conducted* away from it. It will, probably, in a few moments partially recover (especially in the case of vulcanite) these properties. This will result from a portion of its electrical charge having penetrated slightly below its surface; again coming to the surface, when the exterior charge is removed by the conductor. This may be called the *residual* charge. It may be removed by the wet cloth, or even by rubbing with the hand, as before. See also Experiments in Art. 115.

The *conductivity* of a wire, or other body, is the *reciprocal* of its *resistance.* That is, if one body, A, offers a *resistance* to the passage of electricity, say of 9, and a second body, B, a *resistance* of 1 only, the *conductivity* of B is 9 times as great as that of A.

93. List of Conductors in the order of their conducting powers, those nearer the top being the *best* conductors, those nearer the bottom the *best* non-conductors or *insulators*, arranged according to Matthieson's most recent experiments.

Silver.
Copper.
Gold.
Zinc.
Platinum.
Iron.
Tin.
Lead.
Mercury.
The rest of the Metals.
Charcoal or Coke.
Acids.
Saline Solutions.
Sea Water.
Rarefied Air
Melting Ice.
Pure Water.
Stone.
Dry Ice.
Dry Wood.
Porcelain.
Dry Paper.
Wool.
Silk.
Glass.
Sealing-wax.
Sulphur.
Resin.
Gutta-percha.
India-rubber.
Shell-lac.
Paraffin.
Ebonites.
Dry Air.

94. A Non-Conductor or Insulator is a body therefore whose *resistance* is so great as practically to prevent the passage of the electricity to *contiguous* bodies. Such bodies are said to be *insulated* (from Latin *insula*, an island), that is, cut off from connection with the electrified body, as an *island* is cut off from the mainland. *Insulators* or non-conductors differ from conductors *quantitatively*, that is, in degree only; and not *qualitatively* or in *kind*.

95. To Insulate a Body is to support it on a column of *glass*, *vulcanite*, *gutta-percha*, *gum-lac*, *resin*, or some other *non-conducting* substance, or to suspend it by means of *silken* or other con-conducting fibres, so that no electricity can *escape* from it to the ground, or to other adjacent bodies (see figs. 39, 40, 45, 46).

96. Methods of Insulation.—Various modes and contrivances for *insulating* bodies according to the conditions required by the particular experiment have been devised. Several of these, as those for supporting *stationary* bodies, as the human body, a cylindrical and a spherical conductor, during *electrification*, are shown by A, B, C, and D, fig. 45. No further explanation will be required beyond that contained in the descriptive key to the diagram.

Care should be taken that all *glass* apparatus used for *insulation*, especially when not protected by a coating of *shell-lac varnish*, should be kept well *warmed*, more particularly in *class-rooms*, or where many persons are present.

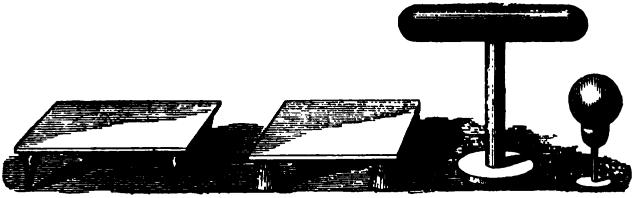


Fig. 45.—SHOWING VARIOUS FORMS OF INSULATING STANDS.

A, Insulating stool, consisting of well dried mahogany top, supported by four *glass* legs, as supplied by the instrument makers.
B, Temporary insulating stool, four common tumbler glasses serving as legs.
C, Metallic cylinder supported by *glass* rod on wooden or iron foot.
D, Metallic sphere supported on *wine glass* or *goblet*.

Fig. 46 will supply the practical student with a hint for an *inexpensive* mode of *insulating* certain forms of *movable* apparatus, as a wooden lath, a metal rod, etc.

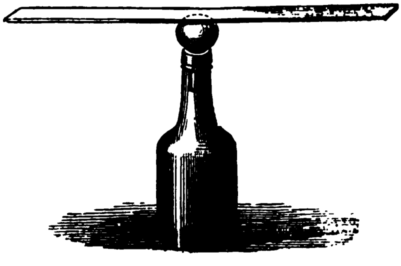


Fig. 46.—INEXPENSIVE SUPPORT FOR INSULATING WOODEN LATH OR FLAT METAL ROD. *Insulating* stand consisting of inverted Florence flask fitted into neck of common wine bottle.

Where perfect *freedom of motion* is required, the insulated body may be *suspended* by *silk* threads, as shown in fig. 41.

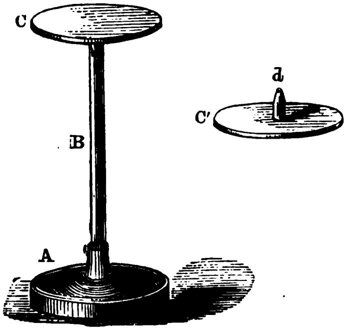


Fig. 47.—Insulating Stand.

A, Wooden or iron foot;
B, glass tube;
C, Movable circular wooden top;
C′, Wooden table top *inverted* to show central peg (*d*).

Fig. 47 shows a convenient form of insulating table, consisting of a round wooden top C and C′ (well baked mahogany, polished or varnished, the best), fitting by a central peg, *a*, into the top of a glass tube, B, 6 to 9 inches long and $\frac{3}{4}$ inch in diameter, supported below by an iron or wooden foot, A.

97. Bodies are not Absolutely Positive or Negative. — At first sight it might appear that each body, according to its nature, was either permanently positive or permanently negative. This, however, is not so, certain bodies, as shown in Art. 98, becoming *positive* or negative according to the nature of the material with which they are *rubbed.*

98. List of Positive and Negative Bodies.—The following is a list of bodies arranged according to the order in which they become *positively* or *negatively* electrified on being *rubbed* together, the *higher* body on the list always becoming *positive* towards the *lower,* and the *lower, vice versâ,* always becoming *negative* to the *higher.*

1. Cat's skin.
2. Flannel.
3. Ivory.
4. Rock crystal.
5. Glass.
6. Cotton.
7. Paper.
8. White silk.
9. Black silk.
10. The dry hand.
11. Wood.
12. Metal.
13. Caoutchouc.
14. Sealing-wax.
15. Resin.
16. Amber.
17. Sulphur.
18. Gutta-percha.
19. Collodion.
20. Gun-cotton.

It may, however, be noticed, that no two authorities agree precisely as to the exact position of several of the above bodies on the list. This is no doubt owing to the difficulty of ensuring absolute identity in the *chemical* composition, temperature, and other *physical* and *mechanical* conditions of the bodies experimented upon. The student is strongly recommended to study the order of the above list, *practically* with the aid of the *inexpensive* and *readily constructed* apparatus described in the body and *Appendix* of this book (see Art. 110).

99. Effect of the Nature of the Surface on the Electrical State of the Rubbed Bodies.—As previously indicated, the electrical state of the rubbed bodies varies with the physical and mechanical condition of their respective surfaces.

EXPERIMENT I.—Rub a small disc of *polished* with a similar disc of *roughened* glass. The *polished* glass will become *positively*, the *roughened* glass *negatively* charged.

EXPERIMENT II.—Rub two similar pieces of warmed *silk* ribbon (cut from the same strip), so that the one shall be rubbed across the other. The one which is rubbed *lengthwise* will become *positive*, the one which is rubbed *crosswise* will become *negative*.

As a general rule it would appear that when two *similar substances* are rubbed together, that that body, the *particles* of which are most easily *displaced*, is the one which usually becomes *negative* to the other.

100. One kind of Electricity cannot be developed without the other.—All the experiments hitherto described tend to show that one kind of electricity cannot be developed without the other. Whenever two bodies are properly tested after being rubbed and electricity developed, the one body is found to be *positively* and the other *negatively* electrified, and no method has yet been able to be devised by which *one kind* of electricity *only* is developed. It is therefore inferred to be a *general law* that *one kind of electricity cannot be developed without the other.*

101. Equal Quantities of the Two Kinds of Electricity are always separated or developed together at

the Same Time.—This law was first demonstrated by Faraday, who also first devised the following experiments:

Experiment I.—(*a.*) Fit a small *flannel cap*, provided with a *strong silk* thread attached to its side, to the end of a stout rod of *shell-lac* (see fig. 48)

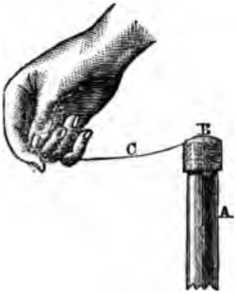


Fig. 48.—Simple Apparatus for proving that Equal Quantities of the two kinds of Electricity are developed at the same time.
A, End of shell-lac rod.
B, Flannel cap.
C, Silk thread for turning the cap rapidly round A, so as to develop the *two* electricities by friction.

(*b.*) Warm the *shell-lac* and *flannel*, and then draw the flannel cap several times round the shell-lac rod by the *silk* thread.

(*c.*) Quickly remove the *flannel cap* by means of the *silk* thread and test by *gold-leaf electroscope* (see Art. 113), it will be charged with *positive* electricity.

(*d.*) Immediately test the *shell-lac rod* in the same manner; it will be found to be charged with *negative* electricity.

(*e.*) Repeat the processes described above in paragraphs (*a*) and (*b*), and test the end of the *shell-lac* rod and *flannel cap* before *separating* them. *No apparent effect* is produced on the leaves of the electroscope.

The inference is, therefore, that the effect produced on the leaves of the electroscope by the *positive* electricity of the *flannel* is exactly *neutralised*, by the effect of an *equal* amount of electricity of the *opposite* kind on the surface of the *shell-lac.*

Experiment II.—(*a.*) Rub a piece of *resin* against a piece of *glass*, having previously attached a *silk* thread to each.

(*b.*) Suspend the excited *glass* in the middle of an insulated, hollow, metallic, *unelectrified* vessel, as shown in figs. 60 and 61. The *outside* of the *insulated* vessel immediately becomes charged with *positive* electricity, as proved by its action on the leaves of a gold-leaf electroscope.

(*c.*) Remove the *excited glass*, taking care it shall *not touch* the metallic vessel, *discharge* the electricity of the *glass* then rub the *resin* and the *glass* together as before.

(*d.*) Now let down both the excited *glass* and the *resin* by their respective *silk* threads into the *unelectrified* vessel, taking care that they neither touch each other nor the sides of the vessel. On testing the *outside* of the vessel containing the excited glass and resin, it will now be found quite *neutral*, no apparent effect having been produced.

(*e.*) Carefully remove the *resin*, taking care nothing touches either the glass or the resin. The outside of the vessel will immediately become charged with *positive* electricity as in the first case described in paragraph *a*.

The inference therefore is that an *equal* quantity of *negative* electricity developed in the *resin* counteracts the *inductive* influence of the *rubbed glass* on the walls of the vessel.

102. To Determine the Kind of Electricity with which a Body is Charged.—The student will already have learnt practically that all that it is necessary to do, in order to determine the *kind* of electricity with which a body is *charged*, is to bring it *near*, or, if the charge is very *feeble*, into *contact* with a freely suspended insulated pith ball *charged* with a *known kind* of electricity, or the *disc* of a gold-leaf electroscope similarly charged, when if the pith ball be *repelled*, or the gold leaves of the electroscope be made to *diverge* more widely, the body is charged with the *same kind* of electricity as that of the electroscope. If, on the contrary, the pith ball is *attracted* or the gold leaves tend to *collapse*, the body is *neutral* or charged with the *opposite* kind of electricity to that of the electroscope (see Arts. 113-115).

103. Hypotheses or Theories of the Nature of Electricity.—The student having made himself familiar with many of the *fundamental* though simple *phenomena* of electricity is now in a position to study and appreciate the *hypotheses* built up by natural philosophers to explain the nature of the *causation* by which these phenomena are immediately produced.

Three *hypotheses* have been proposed to explain the nature of the *causes* immediately giving rise to electrical phenomena, viz.:—

(1.) The *two-fluid* theory of Symmer, which is most generally accepted as giving on the whole the best explanation of the origin of *most* electrical phenomena.

(2.) The *one-fluid* theory of Dr. Franklin.

(3.) The *molecular* or *Electricity a Mode of Movement* theory which is daily gaining more acceptance in the minds of modern physicists, but which cannot yet hope to supersede its more generally accepted rival *two-fluid* theory.

104. The Two-Fluid Theory of Electricity supposes:—1. That *all* bodies in their *normal* or *unelectrified* state are charged with *equal quantities* of *two* peculiar *imponderable*, highly *subtle*, *self-repulsive* fluids, which are respectively termed the *positive* and *negative* fluids or electricities.

2. That *each* body possesses an *inexhaustible* supply of *each* of these fluids, that is, a supply so *great* that by no process whatever could it be *entirely deprived* of the *whole* of either one of these fluids.

3. That though each *kind* of *fluid* or electricity is *self-repulsive*, that is, *repels* its *own kind* of electricity, the *opposite* kinds mutually *attract* each other.

4. That though no body can be *entirely* deprived of the *whole* of either its *positive* or its *negative* fluid, yet it may by suitable means be deprived of a *portion* of *either* of these fluids.

5. That it is possible for a *portion* of *either* of its electric fluids to *pass* from one body to another, in which case the *electric equilibrium* is disturbed, and the body is said to be *charged* or *electrified* with that *kind* of electricity it possesses in *excess*.

6. That it is possible for that portion of the electricity which is in *excess* in the one body to *pass* over to, and *neutralise* an *equal* quantity of the *opposite* kind of electricity in excess in a second body, and thus restore *electric equilibrium* in both of the bodies.

7. That the *act of electrification* by *friction* consists in the partial *separation* of the *positive* and *negative* fluids in each body, so that the *whole* of the positive electricity

separated in the two bodies rubbed together goes to the *one* body, and the *whole* of the *negative* electricity thus *separated* goes to the other body.

8. It is also assumed that *matter* charged with *excess* of either kind of electricity obeys the same laws of *attraction* and *repulsion* as the *electricities* themselves.

The *fluid* formed by the *combination* of the *positive* and *negative* fluids in *equal* quantities is frequently termed the *neutral electrical fluid.*

The *electric* two-fluid theory *differs* from the *magnetical* two-fluid theory; the former assuming that the fluids are more or less separable, not merely from the *molecules,* but also from *masses* of matter; the latter assuming that the magnetic fluids are absolutely *inseparable* from the molecules with which they are associated.

105. The One-Fluid Theory of Electricity supposes:— 1. That all *bodies* in their *normal* or unelectrified state are charged with a given definite amount of a peculiar, imponderable, highly *subtle, self-repulsive* fluid, the quantity of the electric fluid belonging to each substance depending upon its *specific nature.*

2. That when, by *friction* or other means of *electrification,* a portion of the electric fluid becomes *separated* from one body and *passes* into another, the second body containing the *excess* is said to be charged *positively,* and the *first* in which there is a *deficiency* is said to be charged *negatively.*

3. That two bodies, each containing an *excess* of the electric fluid, *repel* one another; but that one body containing an *excess* is *attracted* by another body containing a *deficiency* of this fluid.

4. That two bodies each of which is *deficient* of its *normal* quantity of the *electric fluid repel* each other.

5. That two bodies, in one of which there was an *excess* and in the other an *equal deficiency* of the electric fluid, would, on being brought together, first *attract* and then *neutralise* each other, *electric equilibrium* being simultaneously restored in both bodies.

It was in reference to this theory that the terms *positive* and *negative* electricity were first used.

106.*The "Electricity a Mode of Motion" Theory.—Modern physicists have, extending the analogy of the "molecular theory of heat," proposed a "molecular movement" theory of electricity. It has accordingly been suggested that the two *opposite* kinds of electricity may be supposed to be due to two different kinds of motion of the particles of bodies more or less analagous, say to those of *light polarised in different planes.*

The *division* of an electric charge may also be regarded as analagous to the division of velocity which takes place when a body in motion *strikes* a body at rest, or moving in the opposite direction.

It has also been suggested that the phenomena of electricity may be due to the *interstitial ether* which is supposed to be diffused through the pores of all material substances; and that this *ether*, in addition to the *vibratory* motion which produces *light*, causes a *translatory* movement which gives rise to the phenomena of electricity.

CHAPTER VI.

ELECTROSCOPES AND ELECTROMETERS.

107. Instruments for Indicating and Measuring Electrical Force.—All instruments in general use for indicating the presence or measuring the intensity of *statical* electricity, are founded upon the principles of *attraction* and *repulsion.* Such instruments consist of devices, by means of which the *mechanical work* done through the agency of the forces of *attraction* or *repulsion*, generated by the electricity to be *tested*, can be more or less accurately *measured* by the *divergence* of *pith balls*, *gold leaves*, or other exceedingly light objects; by the *deflection* of magnetic or light metallic needles;

or by the *torsion* of silk fibres, or very fine metallic wires, to the lower extremities of which are suspended index needles, the readings being rendered much more *delicate* by the application of exceedingly light *mirrors*. These mirrors are so applied to the needles as to reflect the light *focussed* from the flame of a paraffine lamp on to a graduated scale placed at a distance.

Probably in no department of practical or theoretical science has greater ability and ingenuity been displayed during the last fifteen to twenty years than in the devising and constructing of *apparatus for electrical measurements;* and the thanks of the whole scientific world are due to Professors Sir W. Thomson, Foster, Jenkin, Clerk Maxwell, Matthieson, and Balfour Stewart, and Messrs Joule, Siemens, Varley, and other English electricians for the impulse they have given to scientific research in this direction, and for the great resources they have opened out to *practical telegraphy,* and through it to commerce.

108. Electroscopes (from Gr. *elektron,* amber, and *skopeo,* I view) are instruments used for determining the *presence* and *kind* or *quality,* but *not* the *quantity,* of *free* electricity in a substance.

Electroscopes, of which there is an immense variety, differ greatly in construction and material. They, however, in general, consist of one or more exceedingly *light* bodies, as straws, pith balls, gold leaves, etc., each of which becoming charged, either *inductively* or by direct *communication* with the body to be *tested,* with *similar* electricity, *repel* each other, thus proving the presence of *free* electricity in the body under examination.

Though electroscopes are intended to indicate the *presence* and *kind* only of *free electricity,* they, by the relative *degree* of the divergence of their *leaves* or *pith balls,* indicate *roughly* the comparative intensity of the electricity of the bodies *tested.*

The following is a list of the electroscopes most generally used in this country:—The Electric Pendulum (see fig. 41), the Needle, the Double Pith-Ball, the Bennett's Gold-Leaf, and the Volta's Condensing Electroscope.

When experiments of moderate delicacy have to be made, it is necessary to protect the pith balls from currents of air; this is generally done by means of a suitable form of glass jar, which also serves to *support* and *insulate* the gold leaves, etc.

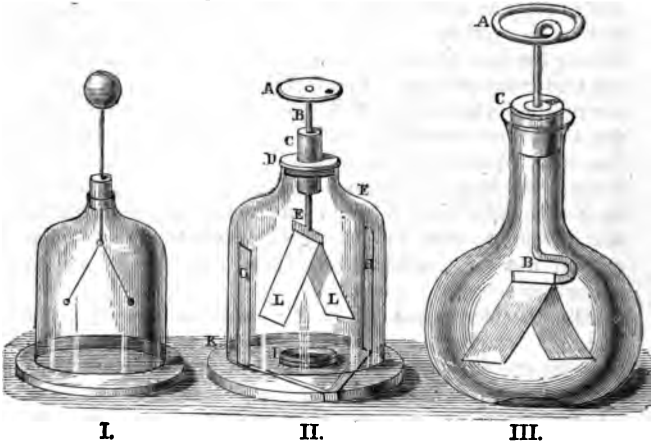


Fig. 49.—ELECTROSCOPES.

I. Pith-ball Electroscope.
II. Gold-leaf Electroscope. A, Metal disc; B, metal pillar insulated by means of vulcanite cork, C, fitting into wooden *air-tight* cap, D, which closes mouth of bell jar; E, cross-piece supporting *gold leaves*; F, bell jar; GH, slips of tin-foil connecting inside of the jar with the ground; I, glass vessel containing pumice stone soaked in sulphuric acid; K, wooden stand; L L, gold leaves.
III. Simple and inexpensive form of Gold-leaf Electroscope, as described in Art. 111. A, *spiral* of wire in place of *disc;* B, wire *bent* to form cross-piece; C, disc.

109. The Pith-ball Electroscope (I., fig. 49), consists of a wooden stand with circular groove in which is placed a glass *bell jar* supporting a *brass ball* (or metal disc) and wire, which, passing through a cork or vulcanite stopper in the neck of the bell jar, supports two pith balls suspended from the lower end of the wire by means of *cotton* or *linen* (not silk) threads.

110. The Gold-leaf Electroscope (II., fig. 49), consists of a *metal disc* A (with small hole for connecting, when necessary, with bodies to be tested), to which is attached the *brass wire* B E, supporting the *metal cross-piece* E, to which the two *gold leaves* L L are attached.

The metal disc and pillar are retained in their places by the *vulcanite fitting* C, which is inserted in the air-tight polished *wooden cap* D, which closes the mouth of the glass jar F.

The bell-jar is fitted into a circular *groove* in the mahogany *stand* K, at the middle of which is placed a glass vessel containing strong sulphuric acid for the purpose of keeping the interior of the jar quite *dry*. Two slips of *tin-foil* are also gummed against the sides of the jar and the wooden base, so that the interior of the jar may be brought into connection with the ground, in order to discharge the electricity from the two *gold leaves* when they have been *repelled* so far as to touch the sides of the glass.

111. To Construct a Cheap Gold-leaf Electroscope.—The following instructions for making a *cheap gold-leaf electroscope* were recently issued to the students receiving practical instruction in physics at the science schools, South Kensington:

Take a glass flask, *fit* with cork, *bore* cork and *fit* with piece of glass *tube* 1 inch long.

Cut *zinc disc* 1½ inch diameter, drill and solder to a straight brass wire 8 inches long, drill *hole* in edge of disc.

Fill glass tube with flake shell-lac, previously rinsed with alcohol, warm wire and push through, as in III., fig. 49.

Clean wire and solder on *cross-piece* of wire, cut away cross-piece to ¾ inch in length.

Cut *two strips* of Dutch *metal,* say 3 inches long and ¾ inch wide, *gum* each edge of *cross-piece,* shade from air currents, and place in *flask.*

Fig. 49, III., shows a still simpler form of construction in which the soldering to tyroes, the most troublesome part of the work, is dispensed with, the upper part of the wire being *bent* into the form of a flat spiral, and the lower end into a convenient form of cross-piece.

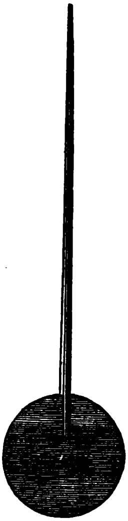


Fig. 50.—Proof-plane. Extemporised of split whalebone and gilt paper, or card covered with tin-foil, or coin for disc.

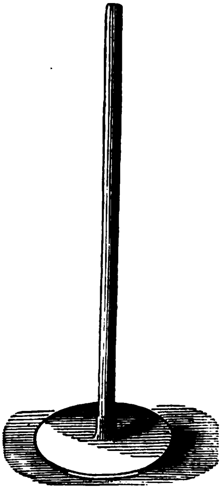


Fig. 51.—Proof-plane, consisting of metal disc and glass handle.

112. The Proof-plane is an instrument used for *collecting* small quantities of electricity from the surface of bodies to be *electrically tested,* which have a *higher potential* than that of the proof-plane itself. It usually consists of a small circular disc of *metal,* of *gilt* paper, or of card covered with *tin-foil*, attached to an *insulating* handle of glass, sealing-wax drawn out into a thin rod, shell-lac or ebonite, or even of well-dried whalebone. Fig. 50 sufficiently explains its construction.

When the *collector* takes the form of a small *gilt* or a light *metallic* ball, supported by a *silk* thread, it is termed a *carrier ball.* For cheap proof-plane, see Appendix.

113. To Use the Gold-leaf Electroscope.—The electroscope is used (1) to ascertain whether a body is electrically *excited* or *neutral*; (2) to ascertain the *quality* or *kind* of electricity with which a body is charged. In the *first* case all that is necessary is to bring the *object* to be *tested slowly* nearer and nearer the disc of the electroscope until, if *necessary*, it is made to touch it. If the object be powerfully charged, the *gold leaves* will begin to *diverge* when it is at a considerable distance from the electroscope. Unless care be taken in such a case, and especially if the instrument be a sensitive one, the *gold leaves* will be torn, and the instrument rendered useless. It is in general, unless the body be very *feebly* charged with electricity, better to test it by means of the *proof-plane*, as shown in Art. 156, and figs. 82 and 92.

If, as in the *second* case, it be required to determine the *kind* of electricity with which the body is charged, the *gold leaves* of the electrometer themselves must first be *charged* with a *known kind* of electricity, then if on the approach of the electrified body to be tested, or a *proof-plane* charged with a *portion* of its electricity, the gold leaves become *still more divergent*, the body is *electrified* with the *same* kind of electricity as the gold leaves are *known* to be charged with; if, on the contrary, they become *less divergent* as the body *approaches* the disc, the body is charged with the *opposite kind* of electricity.

114. To Charge a Gold-leaf Electroscope with a given kind of Electricity by Induction.—(1.) Bring a *silk rubbed glass rod* nearly into contact (but not so near as to permit of the electricity's passing directly from the rod to the electroscope) with the cap or disc of the electroscope, the *gold leaves* will become *divergent* (see B, fig. 52). (2.) *While the glass rod* remains *nearest* the *cap* of the electroscope, touch the *metal cap* with the finger, then *remove* the *finger*. (3.) *Having removed the finger*, now *remove* the excited glass rod. The *gold leaves* will immediately *diverge* by the *repulsion* of the *negative* electricity they contain.

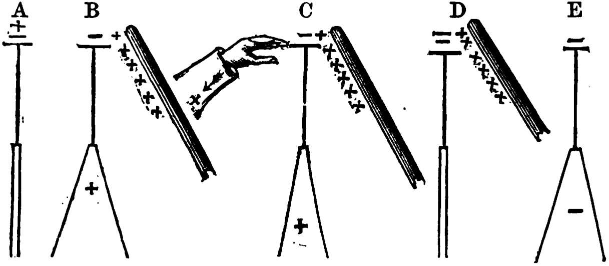


Fig. 52.—Illustrating the Method and Theory of Charging the Gold-leaf Electroscope with Negative Electricity by Inductive Action of Excited Glass Rod charged with Positive Electricity.

A, Shows *disc* and *gold leaves* of electroscope in *neutral* condition (electric equilibrium), containing *equal* quantities of *positive* and *negative* electricity.

B, Shows *decomposition* of *neutral* electricity of disc and gold leaves by the *inductive* influence of the *positive* electricity of the *excited* glass rod on being brought *near*, but *not in contact* with disc of electroscope.

C, Shows the escape of the *positive* electricity from the disc, pillar, and gold leaves of the electroscope, when a *path* is opened to it by *touching* the disc with the finger.

D, Shows the *collapsed* condition of the two gold leaves from the escape of their *positive* electricity, the *negative* electricity being *bound, disguised*, or made *captive* by the attraction of the *positive* electricity of the glass rod which *has not yet been removed.*

E, Shows the condition of the disc, pillar, and gold leaves *after the removal* of the excited glass rod has set their *negative* electricity *free.*

A therefore shows the *neutral* state of the electroscope *before*, and E the electric state of the electroscope after being charged inductively by the glass rod, while B,C,D indicates the electric *changes* taking place *during* the process of *charging.*

To charge the electroscope with positive electricity, repeat the experiment with a *vulcanite* rod rubbed with *flannel.* In each case the gold leaves will become charged *inductively* with the *opposite* kind of electricity as that of the body by means of which they are charged. Charging bodies with electricity by this method is sometimes described as *entrapping* electricity.

Though the theory of this process will be best understood by the student after he has read the chapter on *Induction,* yet it is hoped he will have little difficulty in following it intelligently when he has carefully examined fig. 52 and its descriptive key.

115. Experiments with the Gold-leaf Electroscope.—The student is recommended to perform the following experiments, also those described in Arts. 80 and 83, and also others he may readily devise, testing the *kind* of electricity with which the various bodies are charged, and roughly the relative intensity of the charge, also the relative *conducting* power of the bodies.

EXPERIMENT I.—On *conductivity.* "Fasten one end of *thread* to hole in cap of electroscope, and other end to *insulating* support, charge proof-plane and approach to far end of thread." Observe *if* and to *what extent* the gold leaves *diverge.*

Repeat this experiment with *wet* and dry cotton and linen thread, with wire, wet and dry silk, and with thin rods of shell-lac, whalebone, etc.

EXPERIMENT II.—Grind warm *coffee* berry in a mill, receive the warm powdered coffee in a warm glass tumbler, and sprinkle the fresh ground coffee from the glass on to the disc of the electroscope. The gold leaves will *diverge.* Test the *kind* of electricity developed in the coffee.

EXPERIMENT III.—Rub cap of electroscope with warm *fur* fastened to end of glass rod, quickly remove the *fur.* The gold leaves will diverge. Test the *kind* of electricity.

EXPERIMENT IV.—Break up roll *sulphur,* powder in small mortar, drop a little of the powdered sulphur on the cap of the electroscope. Test *kind* of electricity developed.

Experiment V.—Take *warm* wine-glass, half fill with *dry mercury*, connect mercury with electroscope by means of a wire, stir the mercury with dry feather. Test the *kind* of electricity with which the gold leaves *diverge*.

Experiment VI.—Test for kind of electricity developed in (1) *brown paper* rubbed with *flannel* and with *india-rubber.*
(2.) *Sealing wax* rubbed with *flannel* and with collodion.
(3.) *Smooth glass* rubbed with *silk* and with cat's fur.
(4.) *Ebonite* rubbed with *silk* and with *amalgamated silk.*
(5.) *Smooth* and *rough* glass rubbed with *silk.*

Write out your result in these experiments, also the inference to be drawn from them.

Experiment VII.—Place two large *dry corks* in the mouths of two perfectly dry bottles, warm one of the corks, and using the bottles as handles, press the surfaces of the two corks sharply together and separate quickly. Touch the cap of a sensitive electroscope with each cork, and determine with what *kind* of electricity the *warm* and the colder cork were respectively *charged.*

Experiment VIII.—Blow *dry* powdered chalk from a small pair of paper bellows against the cap of the electroscope. Test the *kind* of electricity developed.

Experiment IX.—Project fine *steel filings* against the cap of the electroscope, so that they shall immediately *glance off* and leave the cap free of them. Test the *kind* of electricity as before.

116. Gold-leaf Condensing Electroscope, see Art. on Condensers.

117. The Peltier Electroscope, fig. 53, is a form of needle electroscope. In its simplest form it consists of a *vertical* brass pillar, B C, expanded in the middle into a thick *ring* A, and at its summit into the brass ball, B. It is supported at its base by a fitting of *vulcanite* let into a wooden post. From the *centre* of the metallic ring is balanced by the *steel* point D (which is screwed into the bottom of the ring), the light flat *feebly* magnetised compass needle, *n, s,* to the top of which is fastened at right angles the long thin *light* rod or *needle* of brass, or still better of *aluminium* wire, E F.

The *magnetic polarity* of the compass needle should be barely sufficient to cause it to come to rest in the plane of the magnetic meridian. The sides of the instrument are protected by a glass cylinder from currents of air.

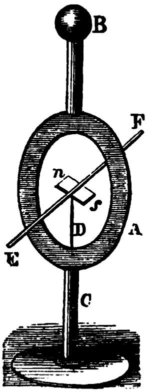


Fig. 53.—The Peltier Electroscope.

ABC, *Metallic* pillar expanded at the middle into a *ring*.
D, Vertical steel point.
EF, Light brass or *aluminium* wire, *n, s,* magnetised needle supporting EF, and *directing* it when not electrified.

To use the instrument.—(*a.*) Place it so that under the influence of the magnetised needle, *n, s,* the wire, EF, shall *almost* be in contact with, but still shall not touch the sides of the ring A.

(*b.*) Bring the *electrified* body to be tested into contact with the metallic knob B, the instrument being in a *neutral* state.

The electricity will thus (the electrified body being at a higher *potential* than the instrument) flow through the knob into the metallic ring and wire needle EF.

The sides of the ring thus becoming charged with the same kind of electricity as that of the needle will *repel* it, thus indicating its charged or *electric* condition; the degree to which it is *repelled* also indicates roughly the *comparative intensity* of the electric charge of the body.

With some modifications, as by fixing two metallic *arms* immediately below and at *right angles* to the ring, so the ends of the long light needle EF being bent so as to be brought as near as possible without absolutely touching the arms; and attaching a circular *graduated scale* immediately *below* the arms, this apparatus is converted into a good and useful electrometer, the *Peltier electrometer.*

In the Peltier electroscope the resistance of the *feebly* *magnetised* needle is substituted for that offered by the twisting of the thread in the torsion electroscope.

118. **Electrometers** (from Gr. *elektron*, amber, and *metron*, a measure) are instruments used not only for determining the *kind* of electricity present, but also for *measuring its intensity.*

The *electrometers* most commonly used in this country for *measuring* or illustrating the mode of measuring the intensity of the *free* statical electricity present in a body, are the Henley's Quadrant, the Coulomb's Torsion, the Peltiers, and the Thomson's Quadrant electrometers.

119. **Henley's Quadrant Electrometer** consists (see fig. 54) of a brass pillar *b, c,* to the upper half of which is attached a quadrant *d,* but more usually a semicircle of ivory, wood, or *card* graduated at its outer edge into degrees. To the centre of the quadrant is attached an index of baked wood or straw terminating in a pith ball *a,* and movable on the centre in a vertical plane.

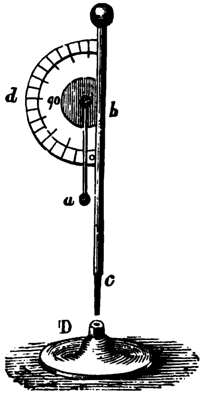


Fig. 54.—Henley's Quadrant Electrometer.
b, c, Metal pillar;
d, graduated semicircle or quadrant;
a, pith ball and index;
D, wooden foot to support electrometer when not in use.

To *use* this instrument all that is necessary (see fig. 54) is to insert the pivot at the lower end of the pillar into a hole drilled for that purpose in the prime conductor or ball of the Leyden jar to be tested, or to place it by means of its foot, so that the lower end of the metal pillar shall be in contact with the body to be tested. The pith ball *a,* and the metal pillar *b c,* thus become charged with the *same kind* of electricity, the *pith ball* and *index* are therefore *repelled,* the degree to which the index rises measuring *roughly* the intensity of the charge. Fig. 55 shows a somewhat different form of quadrant electrometer.

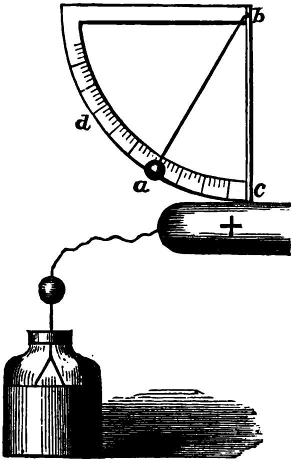


Fig. 55.—Measuring Electric Tension by Quadrant Electrometer.

120.* Coulomb's Torsion Electrometer or Balance consists essentially of a glass case containing a *needle* supported from above by a *thread*, the mechanical resistance to the twisting or torsion of which constitutes the force by which the electrical forces of attraction and repulsion themselves are measured. The *torsion* thread itself is suspended from a *micrometer*, by means of which, and a *graduated scale* on the side of the instrument, the degree of twisting necessary to overcome the repulsive force of the electricity driving the electrified balls (*i* and *k*) at the end of the needle and the collector asunder is determined. The general construction of the instrument will be readily understood by reference to fig. 56.

To Use the Torsion Electrometer.—(1.) Having levelled the instrument, bring the *index* (*c*) of the micrometer and the *gilt ball* (*i*) to their respective zeros.

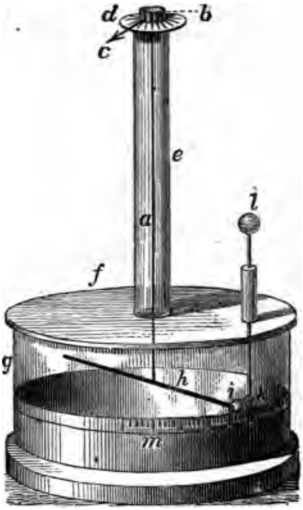


Fig. 56.—Coulomb's Torsion Electrometer.

a, *Torsion thread* of fine silver wire, or fibre of silk or glass attached to *b*.
b, *Milled head* of *pin* supporting *a*.
c, *Index* attached to *b* to show amount of *twisting* undergone by *a*.
d, *Graduated circle* for measuring degree of *torsion* of *a*.
e, Glass tube supporting *micrometer* *b*, *c*, *d*, and *torsion thread a*.
f, Glass *cover* supporting the tube *e* and its contents, with small aperture into which *k l* is fitted by a vulcanite cork.
g, Large glass cylinder protecting *torsion needle* and supporting *f*. This cylinder is in general closed below by a wooden base standing on three *levelling* screws as feet.
h, Light shell-lac, or vulcanite *torsion needle*.
i, Gilt *pith ball* fixed to the *lighter* end of *h*.
k, *l*, Conductor for *charging* *i*, fitting into cover by vulcanite cork. This is frequently made in the form of an ordinary *carrier ball*.
m, Paper *scale* (graduated into degrees) pasted round *g* to show amount of *deflection* of torsion needle and gilt ball (*h*, *i*).

(2.) First charge a *proof-plane* with electricity from the body to be tested, then bring the charged *proof plane* into contact with the collector (*l k*) which immediately imparts a portion of its charge to the needle ball (*i*) and *repels* it.

(3.) Twist the needle and gilt ball back to or within a given number of degrees of the collecting ball (*k*) by turning the milled head (*b*) in the opposite direction to that in which the needle was repelled. The *repulsive force* of the electricity in any two *charged* bodies is proportional to the respective amounts of turning (twisting of the thread) measured in degrees on the two scales necessary to bring the needle back to the same position in each case.

121. **Laws of Electricity.**—The student who has attentively followed this and the preceding chapter must by this time be in a position not only familiarly to know, but to understand the following *qualitative* and *quantitative* laws.

Law I.—Like electricities Repel, unlike electricities Attract, each other.

Law II.—The Attractions and Repulsions between two Electrified Bodies are Inversely as the Squares of their Distance.

Law III.—The Distances remaining the same, the Force of Attraction or Repulsion between two Electrified Bodies is directly as the Product of the Quantities of Electricity with which they are charged.

The two latter laws were established by Coulomb by means of the electrometer just described.

The student should also be able to recognise clearly the respective differences between the forces of Electricity, Magnetism, and Gravitation. See Secs. 29, 30, *Appendix.*

122. **An Absolute Electrometer,** capable of measuring the electric force in definite *units,* has been constructed by Sir W. Thomson, but only the advanced student would be able to comprehend its principles and details.

For Thomson's Quadrant Electrometer, and Bohnenberger's Electroscope, consult Index.

CHAPTER VII.

ELECTRICAL INDUCTION.

123. Electrical Induction. — Whenever an *electrified* body is placed near, but *separated* from, another body (so that its electricity cannot escape from the one body to the other) by a *non-conductor*, the former acts upon the latter: if *neutral*, decomposing its neutral electric fluid; or if it be already electrically *charged*, more or less *disturbing* and *displacing* such charge. To such action the term *induction* is applied.

Electrified bodies act inductively on *all* surrounding bodies.

Induction is therefore the process by which the electricity in one body, separated from another body, acts upon its electricity, so as, if *neutral*, to decompose its neutral fluid, attracting its *opposite* electricity to the *nearer* end, and *repelling* its *similar* electricity to the *more remote* end of the body; or, if the latter body be already *charged*, causes the *displacement* or *re*-distribution of its electricity.

Induction always takes place when *two* or more bodies, at *different electric potentials*, are *separated* by an *insulating medium*.

In the case of a thick cake of *insulating* material, as of glass, vulcanite, etc., we may suppose one electrically excited surface of the cake to act by induction on the other unelectrified surface, through the *dielectric substance* of the cake itself.

Bad conductors are acted upon by *induction less readily*, but more *permanently*, than *good conductors*.

The electrified body by which the induction is set up is termed the *inducing* body, the electricity *separated* by its action *induced* electricity.

124. Experimental Illustrations of Electrical Induction.

Experiment I.—(*a*.) Bring a rod of *vulcanite*, excited by being rubbed with warm *flannel*, near one end of a *wooden lath*, balanced on a Florence flask, and at the other end of which a gold-leaf electroscope is so placed as to be *near*, but *not in contact* with, the lath, as shown in fig. 57.

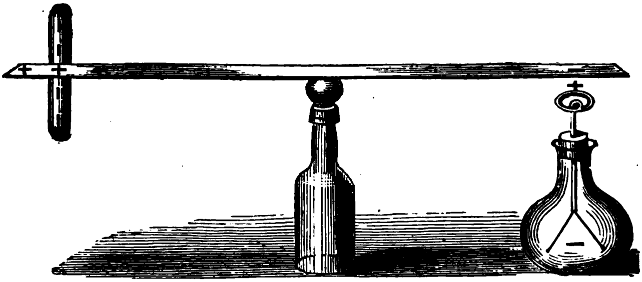


Fig. 57.—Showing Inductive Action of Excited Vulcanite on Insulated Wooden Lath and Gold-Leaf Electroscope.

The end of the lath near the vulcanite will become temporarily charged with *positive* electricity, while the remote end of the lath will become temporarily *negative*. The *negative* electricity of the remote end of the lath, again acting *inductively* on the electroscope, will *attract* the *opposite* electricity to the *cap*, and *repel* the *same* kind to the gold leaves, which thus becoming charged with *negative* electricity will *repel* each other. The whole of these actions and reactions are shown in fig. 57.

(*b.*) Remove the *excited* vulcanite, the separated electricities will immediately *re*combine, the wooden lath and the gold leaves of the electroscope immediately returning to the state of *electric equilibrium*, the latter in consequence immediately ceasing to *diverge*. The ends of the lath and the gold leaves of the electroscope were therefore only *transiently* charged.

(*c.*) Repeat the experiment, but *before* removing the excited vulcanite touch either end of the rod with the finger. On removing the vulcanite the wooden lath will be found to be *permanently* charged with the *opposite* or *positive* electricity.

(*d.*) Instead of touching the end of the lath, as described in the last paragraph, touch the cap of the electroscope with the finger. On removing the vulcanite rod, the wooden lath, and electroscope, the wooden lath will be found to have returned to its *neutral* state, but the leaves of the electroscope will remain *divergent*, because permanently charged with *positive* electricity.

Experiment II.—Bring an excited silk-rubbed *glass* rod *near* one end of an *insulated* unelectrified cylindrical conductor (C), its remote end being in connection with the electroscope (E) by means of a metallic wire (W) proceeding from and inserted in the hole in the *cap*. (See fig. 58.)

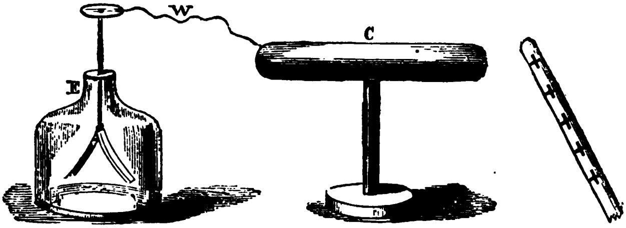


Fig. 58.—Showing Inductive Action of Excited Glass Rod on Cylindrical Conductor (C) standing on Glass Leg, and on Electroscope (E) connected with it by Wire (W).

The gold leaves will now *diverge*, from the *repulsion* of the *positive* electricity from *out* of the conductor *through* the wire *into* the electroscope, by the inductive action of the *glass* rod.

Electrify the conductor and electroscope both *transiently* and *permanently*, as in the last experiment.

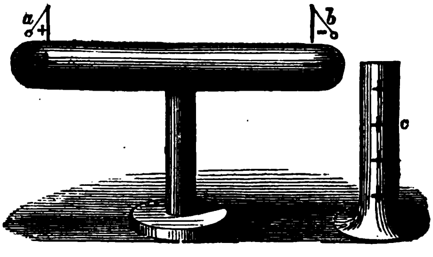


Fig. 59.—Showing Inductive Action of Rubbed Glass Pillar on Neutral Metal Cylinder Mounted on Glass Leg.

Experiment III.—Repeat the last experiment, as in fig. 59, substituting electric pendulums for the *gold-leaf* electroscope, the two ends will become electrically charged, as shown in the figure, the intensity of the *induced* charges diminishing towards the *middle* line, but being a little *nearer* the inducing body than at the *medium* line.

Experiment IV. — Test electrical condition of table, when electrical machine is at work, by means of *proof-plane* and gold-leaf *electroscope.*

Experiment V.—Test electrical state of *air* and of *walls* of room, when a powerful machine is at work, with proof-plane or cotton wick attached to end of long pointer held in the hand by means of folds of vulcanised india-rubber, the *metallic disc* and the cotton being connected with gold-leaf electroscope by thin copper *wire.*

125. The Induced Electricity in one Body acts Inductively on Adjacent Bodies.—If a silk-rubbed glass body A, or a *positively* electrified insulated conductor, be placed *near* an insulated *un*electrified metallic cylinder D (see fig. 59), it will act *inductively* upon it, attracting its *negative* and *repelling* its *positive* electricity, as previously explained.

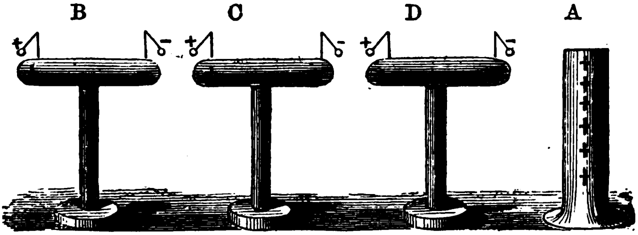


Fig. 60. — Showing Action of one Inductively Electrified Body on Another.

A, Inducing body (excited glass vessel).

B, C, D, Insulated conductors charged with induced electricity. The disturbance of electrical equilibrium is shown by the electric pendulums mounted on the ends of the conductors.

If now a second similar *un*electrified insulated conductor (C) be placed near the first, the end most remote from the *inducing body* will act similarly upon it. If, again, a third insulated *neutral* conductor (B) be placed near C, it will be acted upon in a like manner, and so on.

126. The Induced Charge is equal to the Direct Charge produced by Contact of the Inducing Body.—Faraday demonstrated this fact by the following device usually known as the *Ice Pail Experiment:*—Faraday connected the outside of an *insulated* metallic ice pail (V), about 10 inches high, and 7 inches in diameter, with the cap of a *gold-leaf electroscope* (E). Into the interior of the neutral vessel he let down, so as *not* to touch its sides, a *positively* electrified brass ball (B), by means of a perfectly dry white *silk* thread (S) 3 or 4 feet long. Immediately the electrified ball entered the vessel, the gold leaves began to *diverge,* obtaining their *maximum* divergence when it arrived at about 3 inches below the mouth of the vessel—the degree of divergence remaining *unchanged* as the ball sank *deeper*

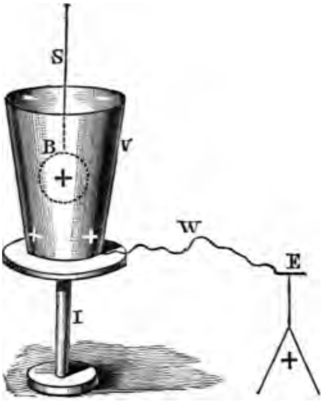


Fig. 61.—Faraday's Ice Pail Experiment.

V, Metallic vessel charged *positively* on its *outer,* and *negatively* on its *inner* surface by the induction of B.
B, Brass ball, charged with positive electricity.
E, Gold-leaf electroscope.
W, Wire-connecting vessel, with electroscope.
I, Insulating stand.

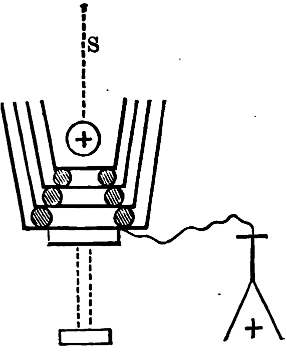


Fig. 62.—Faraday's Four Ice Pails Experiment.

Consisting of four metallic vessels, three of which are arranged within, and *insulated* from each other by balls of glass, shell-lac, or vulcanite. Other arrangements the same as those of fig. 61.
S, Silk thread.

into the vessel. He now removed the electrified ball entirely away from the vessel, the gold leaves immediately *collapsed.*

On repeating the experiment the gold leaves diverged as before. The *electrified* ball was now allowed to *touch* the *inside* of the vessel; the gold leaves still continued to diverge as before contact. On *removing* the ball it was found to have lost all trace of electricity. The electricity had passed from the ball into the vessel, which was now electrified by *direct contact.* The equal divergence of the gold leaves, *before* and *after* contact, therefore, proves that the quantity of *induced electricity* received by the exterior of the vessel was exactly *equal* to the quantity it received by *direct* conduction.

The *neutralization* of the walls of the vessel, on the *withdrawal* of the electrified ball, proves that the quantity of *negative* electricity in the *inner* wall of the vessel must have been just equal to that of the *positive* electricity distributed over the surface of the *outer* wall, under the inducing influence of the positively charged ball.

Faraday afterwards modified this experiment by the use of *four ice pails,* arranged as shown in fig. 62, with the following results:—

(1.) When the *electrified ball* was let down to a distance of 3 inches from the bottom of the *inner* vessel it produced the same effect as when *one* pail only was used.

(2.) When the *electrified ball* was let down into contact with the *bottom* of the *inner* vessel the gold leaves still *diverged,* as in the case of the first experiment with *one* vessel only.

(3.) When the *inner* vessel, now *charged* by contact with the electrified ball, was removed by means of *silk* threads, the gold leaves *collapsed.*

(4.) When the inner vessel, thus charged, was again let down (by the silk threads) to the place it previously occupied, the gold leaves again *diverged* as before.

(5.) On the two *inner* vessels being *connected,* by means of a *wire* let down by a *silk* thread, *no change* in the *divergence* of the gold leaves was produced.

(6.) On similarly connecting — firstly, the *second* and *third* vessels; and, lastly, the second and outermost vessel (in the latter case *all four* vessels being electrically connected)—the *divergence* of the gold leaves still remained *unchanged*

From the above experiments it therefore follows:—(*a*), That not only does one inductively electrified body act on another, but also that no force is *lost* in the transmission of such *inductive* effect from one insulated body to another. (*b*), That the electricity developed by *induction* is *equal* in quantity to that of the *inducing* body.

127. To Charge a Body by Induction.—(1.) Bring a charged body, as a *negatively* electrified rod of *vulcanite*, as near the *insulated neutral* conductor to be charged as possible, without allowing the electricity to *escape* from the *inducing* body.

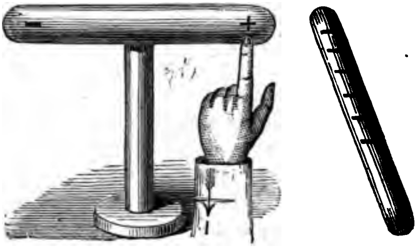


Fig. 63.—Showing Method of Charging Insulated Conductor by Induction.

(2.) While the inducing body is *nearest* the conductor, touch *either end* of the latter with the finger, or a wire connected with the ground; that kind of electricity which is *similar* to that of the *inducing body* will be *driven* out of the conductor into the *earth*, as shown in the diagram. The conductor will thus become charged with the *opposite* electricity to that of the *inducing body*, but in a *bound*, captive, disguised, or *latent* state, under the *attractive* influence of the latter.

(3.) *Having* previously removed the finger, now remove the *inducing* vulcanite rod. The *bound positive* electricity is set *free*, and diffuses itself over the surface of the conductor. (See Arts. "Free" and "Bound Electricity.")

If the conductor be constructed of two equal parts, on separating them *while* under the *inductive* influence of the *electrified* body, and before either of them has been touched by any conducting substance, they will be found to be charged with *opposite* electricities, that of the more *remote* half being of the same kind as the *inducing* body, and the electricity nearer being of the *opposite* kind.

128. To Charge Two Bodies with Opposite Electricities by the Inductive Action of a Body Charged with one kind of Electricity only.—Let the conductor, consisting of two halves, each mounted on a separate glass leg, be acted upon inductively, as described in the preceding Article, the two portions being placed together, so as to form but one conductor. Let them now (while under the inductive influence of the excited glass pillar) be *separated* (see fig. 64.) The *farther* conductor will be charged with the *same* kind, and the *nearer* one with the *opposite* kind of electricity to that of the glass pillar or other *inducing* body.

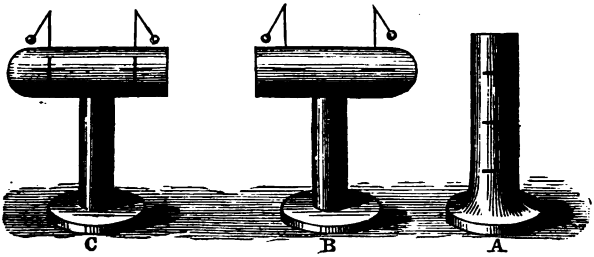


Fig. 64.—Showing Mode of Charging two Bodies with different kinds of Electricity by the Inductive Action of one kind only.

A, Positively charged glass pillar.
B, C, Two halves of insulated conductor after separation, having been *electrified together* as one body.

If the experiment be repeated with *two brass balls* on *glass* legs each ball will become *differently* electrified.

129. Faraday's Theory of Induction by Contiguous Particles.—Before the investigations of Faraday it was usual among electricians to consider the air as insulating bodies, by its *pressure* on their surfaces overcoming the *tension* and preventing the escape of the electricity. Faraday, with his great scientific insight into the nature of physical *causation*, clearly perceived that this was an entirely unsatisfactory explanation of the phenomenon. Accordingly, he was led to examine the general phenomena of induction, which he did with great care, ability, and most distinguished success, establishing the theory, now so generally accepted, known as "Faraday's Induction Theory."

According to this theory the *medium* through which *induction* takes place is not a *passive* but an *active* and *essential agent* in this process, *induction* being, on this theory, a result of the *polarization* of the particles of the medium separating the *inducing* body from the *body* on which it acts.

By *polarization of the molecules* is simply meant the *separation* of the electricities of the respective molecules, so that *one-half* of each molecule becomes *positively* and the other *negatively* charged.

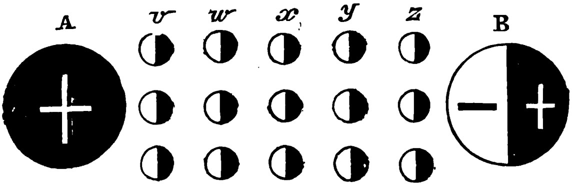


Fig. 65.—Showing Inductive Action of Positively Electrified Body on Neutral Body, through the Polarization of Contiguous Particles, on Faraday's Theory.

A, Insulated brass ball charged with positive electricity.
B, Insulated neutral brass ball under Induction.
v, *w*, *x*, *y*, *z*, Rows of *polarised* molecules. The black shows *positive*, the white *negative*, electricity.

This process will be best understood by reference to fig. 65. Let the insulated brass ball A, charged with *positive* electricity, be supposed to act *inductively* on the insulated *neutral* body B, through the medium of the rows of particles of air, *v*, *w*, *x*, *y*, *z*. The electrified ball A acts inductively on the molecules of the row *v*, *attracting* their *negative* and repelling their *positive* electricities. The *positive* electricity in the *particles* of this row act similarly on those of the next row *w*. In this way the inductive action is *transmitted* to the molecules of the last row *z*, which act upon the *neutral* body B, the *nearer* side of which thus becomes *negatively*, and the more remote *positively*, electrified.

All other bodies, *insulators* (dielectrics) and *conductors*, as glass, shell-lac, the metals, are supposed to act similarly to the particles of air in the case just described.

Faraday explained the difference between *conductors* and *non-conductors* as consisting essentially in the relative facility with which the *particles* of the body under electrification assumed this state of *polarization*. An insulator would thus be a body whose molecules resisted, with more or less force, this state of polarization, but the particles of which, having once become *polarised*, did not readily *discharge* their electricities into each other.

A *conductor*, in like manner, would, according to this theory, be a body whose *contiguous molecules*, under the action of the *inducing* body, would readily become *polarised*, but whose particles thus *polarised* would instantaneously discharge their electricities among each other. It would be easy to show by this theory, did the limits of this little book permit, why *induction* may, through the agency of *contiguous particles*, extend *round a corner*, and not as was formerly supposed act in straight lines only.

The *inductive power* of a body varies with the *medium* through which induction takes place. Thus the neutral body B, fig. 65, would be more or less powerfully affected according to the substance (the *dielectric*), as air, glass, shell-lac, etc., *interposed* between it and the *inducing* body. Hence dielectrics are said to have "specific inductive capacities." See chapter on "Condensers."

130. Induction always precedes Attraction.—If a *positively* electrified body A is presented to a *neutral* insulated pith ball B, the electricities of the ball are first *separated* by *induction*, as shown in fig. 66. The pith ball is then *attracted* by the electrified body, because though *repelled* by the *positive* electricity, also developed in the ball by induction, the force of *repulsion* by its positive electricity is so much weaker, in consequence of its being more remote from the repelling electricity, than is the *attracting* electricity of the *positively charged inducing* body.

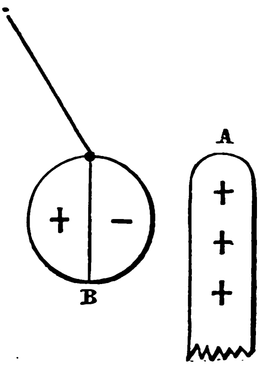


Fig. 66.—SHOWING THAT ATTRACTION IS PRECEDED BY INDUCTION.

A, Positively charged inducing body.

B, Pith ball suspended on *silk* thread attracted by A.

If a point be taken on the *farther* side of the pith ball, which is *twice* the distance from the *inducing* body, to that of another point on the *nearer* side of the ball, the latter will be *attracted* with *four* times the force that the former will be *repelled*.

CHAPTER VIII.

FRICTIONAL ELECTRICAL MACHINES.

131. A Frictional Electrical Machine is an instrument specially constructed for the ready and continuous *generation* or *separation*, by accumulation or temporary storage, of frictional, statical, or Franklinic electricity, for the purpose of charging Leyden jars, batteries, and for other electrical experiments. They in general comprise a tube, cylinder, plate, or disc of *non*-conducting substance, usually *glass* or *vulcanite*, with arrangements for rubbing the same against a *rubber* of silk, leather, fur, etc., and a *prime conductor* or a *collecting* plate for the collection and accumulation of the electricity thus generated. The electrical machines chiefly used in this country are: the electrophorus, the *cylindrical* machine, the ordinary *plate* machine, the Winter's *plate* machine, and more recently the *Holtz's* machine, and the *Bertsch's* machine; a powerful *Hydro-electric* machine has also been constructed.

A large number of a very ingenious and efficient new form of frictional electrical machine, termed an "Ebonite Exploder" (containing two circular plates of *ebonite*), has also been recently constructed by Messrs. Elliott Brothers, London, for exploding mines, torpedoes, etc.

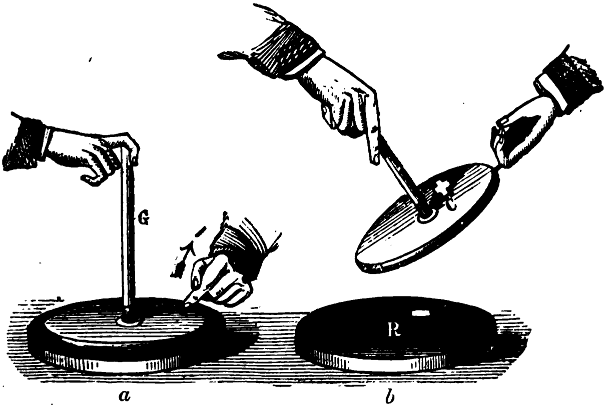


Fig. 67.—Showing Mode of Charging Electrophorus.

132. The Electrophorus (from Gr. *electron*, amber, and *phoreo*, I carry), invented by Volta, is perhaps the simplest form of Frictional Electric Machine. It can, however, only be used when comparatively *small* quantities of electricity are required. It usually consists (see fig. 67) of two parts, viz.:—

(1.) A *lower* disc or *generating* plate (R).
(2.) An *upper* disc or *collecting* plate (C).

The *lower* disc or *generating* plate consists of a flat circular disc of *resin*, *gutta-percha*, or *ebonite* (the last is best), contained within or resting on a metallic dish or plate, which thus bounds its lower surface, and in the case of the resinous plate, also its edges.

This containing or supporting metallic dish is sometimes described as a *third* part of the instrument, under the term *conducting plate* or *sole*.

The *upper* or *collecting* plate usually consists of a circular flat disc of metal (or of *wood* covered with *tin-foil*), and furnished with a central *insulating* handle (G) of glass varnished with shell-lac, or of ebonite. The upper disc should be about two inches less in diameter than the resinous cake on which it rests.

The efficiency of the instrument is greatly increased by (as originally suggested by Mr. Phillips) pasting narrow slips of tin-foil across the surface of the lower (the generating) disc; or by passing a series of brass pins, filed level with the surface, through the substance of the resin or vulcanite into its *sole*. In this case the instrument may be charged and used much more quickly than with the more usual form of the instrument, as it is not then necessary to touch it with the finger, as described in Art. 133.

By means of the *electrophorus*, a very small quantity of *free* electricity can be made (by induction) the means of supply of an indefinitely large quantity of electricity.

The Holtz's and Bertsch's electrical machines—two most powerful modern forms of the electrical machine—consist of most ingenious applications of the principles of the electrophorus.

133. To Use the Electrophorus:—

(1.) *Warm* the instrument so as to make it perfectly *dry*.
(2.) Rub or strike the vulcanite disc (so that its entire

surface shall be acted on) several times in succession with a piece of warm dry cat's-skin, fur, or a roll of silk or flannel, or a fox's tail.

(3.) Take hold, with the right hand, of the insulating handle (C, fig. 67) of the *cover*, and bring it down upon the surface of the *generating* plate, as in *a*, fig. 67; touch the upper surface of the *cover* with the first finger of the left hand, as in *b*, fig. 67; raise it by the insulating handle (having *previously* removed the finger from the cover). The cover or collecting plate is now *charged* with *positive* electricity.

If the charged cover be now brought near the knuckle or any good conductor, an electric spark will be produced. In this way a Leyden jar may be charged; a mixture of oxygen and hydrogen gases may be detonated, as in eudiometrical experiments; and other electrical phenomena may be produced.

To obtain a rapid succession of such charges or sparks, all that is necessary is to quickly replace and remove the cover, as described above in process 3.

The *electrophorus*, when once properly excited, will, in a warm, *dry* room, retain its charge for many days, or even weeks. In a class-room, where many persons are breathing, or where the atmosphere is *not* thoroughly *dry*, it is necessary frequently to re-charge the lower or resinous disc, as described in processes (1) and (2).

134. Theory of the Action of the Electrophorus.—The following is the ordinary accepted theory of the action of the electrophorus:—

(1.) The resinous or vulcanite cake becomes charged with *negative* electricity by the friction of the silk, fur, or other rubbing material employed, the rubber becoming *positively* electrified (see fig. 68).

PROOF.—Bring the excited vulcanite or resinous disc near a pith-ball electroscope, or electric pendulum, charged with *negative* electricity, it will be *repelled*, thus proving it to have been charged with *similar*, that is, *negative* electricity.

(2.) The neutral electricity of the *cover*, on its being brought down on the upper surface of the lower disc or *generating* plate by means of the glass handle, is immediately decomposed by the *inductive* action of the *negative* electricity in the surface of the *vulcanite* disc (see fig. 69). The *positive* electricity of the cover is thus attracted to its *lower* and the *negative* electricity repelled to its *upper* surface.

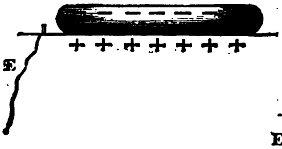


Fig. 68.—Showing Vulcanite Cake charged with Negative Electricity, resting on Metallic Plate or *sole* in connection with the *earth.*

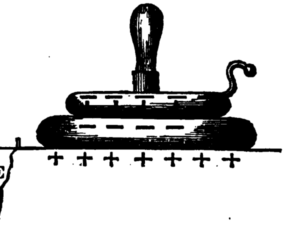


Fig. 69.—Showing Decomposition of Neutral Electricity in Collecting Plate, by *inductive* action of vulcanite or generating plate.

Proof.—(1.) Stand a Henley's quadrant electrometer, with foot on the top of the collecting plate, the index arm immediately *rises* by *repulsion.* (2.) Raise the plate and electrometer from the lower disc by means of the insulating handle, the index arm immediately *falls* because of the *recombination* of the two electricities when removed from the *inductive* influence of the *negatively* charged disc. (3.) Also demonstrate the fact of the *decomposition* of the *neutral* fluid and *recombination* of the two electricities by means of the *proof-plane* and *gold-leaf electroscope.*

(3.) On touching the metallic plate or cover with the finger, its *negative* electricity, repelled by the *inductive* action of the corresponding electricity in the lower or generating plate, immediately escapes (as shown by the passage of the electric spark) through the body of the operator into the earth (see fig. 70). The cover is thus left charged with a surplus quantity of *positive* electricity, or, in other words, becomes "*charged with positive electricity.*"

By means of the electrophorus, or rather by the small quantity of *negative* electricity resident in its *resinous* cake, we are thus enabled to "pump up," as it were, an indefinitely large supply of electricity from the earth as a common reservoir of electricity.

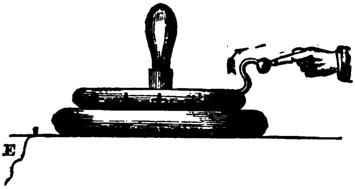


Fig. 70.—SHOWING ESCAPE OF REPELLED NEGATIVE ELECTRICITY FROM UPPER SURFACE OF COLLECTING PLATE, on being brought into connection with the earth through contact with the finger.

135. The Action of the Sole, "conducting plate," or "mould," on which the vulcanite or resinous cake rests, tends both to increase the quantity of electricity and to render it more permanent, as follows:—

(1.) The *negative* electricity at the *upper* surface of the *resinous* cake, acting inductively on the neutral electricity of the *sole, mould,* or metallic plate in connection with the *earth* (by means of a brass chain in connection with the gas or water pipes), decomposes its neutral electricity (see fig. 69), *repelling* its *negative* electricity through the chain or other conductors to the earth.

(2.) The *positive* electricity (fig. 69) thus accumulated in the *mould* or *sole,* acting in return by *induction* on the *negative* electricity on the *upper* badly-conducting surface of the *resinous* cake, causes it (*a*) to accumulate in *larger* quantities, (*b*) to penetrate more deeply into it, (*c*) to be *retained* more *permanently.*

136. Some writers adopt a somewhat different theory of the action of the *mould* or metallic plate on which the vulcanite disc rests. According to this theory the *lower* part of the vulcanite disc itself becomes *positive* under the *inductive* influence of the *negative* charge of its *upper* surface. In this case the *mould* would act chiefly by *conducting* the *repelled* negative electricity from the lower part of the *vulcanite* disc to the ground. Either theory would seem in general to explain the phenomena equally well.

137. The Cylindrical Electrical Machine (see figs. 71, 72, 73) consists of (1) a *glass cylinder* A, supported on two pillars C C, usually of well baked wood, and turning on a horizontal axis B, by means of a handle D; (2), a *rubber* with silk flap I, which is made to press against the revolving cylinder by means of the movable pillar L; (3), a hollow metal cylinder E, termed the *prime conductor,* which is supported by a glass pillar F; the whole being supported on a strong wooden base G. The distance of the prime conductor from the cylinder and the pressure of the rubber are regulated by screws at the base of the machine.

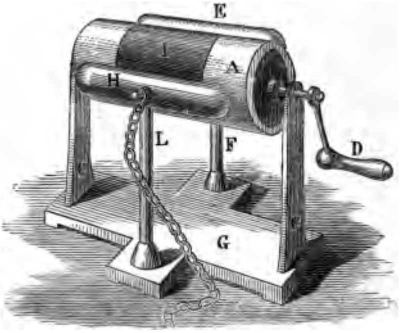


Fig. 71.—Cylindrical Electrical Machine.

One of the chief objects in the construction of an electrical machine is to present the largest possible available surface of glass and silk to friction.

The electricity is *generated* by the *friction* of the silk rubber H, against the rotating glass cylinder A. The *silk flap*, I, tends to prevent the *escape* or diffusion of the electricity generated. The *prime conductor*, E, is *insulated* in order to prevent the escape of the electricity, which would otherwise pass down to the earth as quickly as if it was separated by the action of the machine.

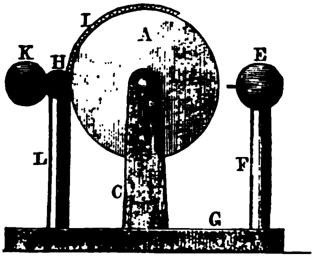


Fig. 72. — VERTICAL PLAN OF CYLINDRICAL MACHINE, seen endwise.

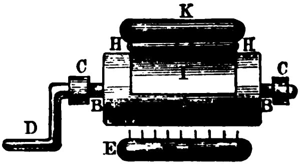


Fig. 73.—BIRD'S-EYE VIEW OF CYLINDRICAL ELECTRICAL MACHINE.

A, *Glass cylinder.*
B, Axis of rotation.
C, Pillars supporting cylinder.
D, Handle for turning machine.
E, Prime conductor.
F, *Glass pillar* supporting prime conductor.
G, Wooden base of machine.
H, Rubber.
I, Flap of oiled silk.*
K, *Conductor* for collecting *negative* electricity.
L, Glass support for rubber.

Before putting the machine into action it is necessary to connect the rubber with the earth, by means of a metallic chain passing from the rubber to the nearest gas or water pipes, so that the *negative* electricity may escape. On putting the machine into motion, sparks, accompanied by a peculiar snapping noise and the odour of *ozone*, are immediately observed.

The quantity of electricity generated with any given number of turns of the cylinder, and consequently the efficiency of the machine, is greatly increased by covering the surface of the silk rubber with a thin layer of *electric amalgam* (Art. 141).

While in *use* the machine should be kept *warm* and dry, and the glass supports and cylinder should be frequently rubbed with warm woollen, silk, or paper dusters to remove the moisture and dust which otherwise tend to collect about the machine and lessen its action. Linen or cotton dusters, which leave a deposit of lint, should not be used for this purpose. Great care should be taken not to place the machine too near the fire and to prevent its being heated unequally, otherwise the glass may crack.

138. The Prime Conductor (see figs. 71, 72, and 73) usually consists of a hollow brass cylinder, with rounded or hemispherical ends, and a line of brass points (½-inch to ¾-inch apart) inserted along the surface presented to the glass. The *prime conductor* is supported by a pillar of glass varnished over with shell-lac. The brass *points*, which are turned towards the glass cylinder, and so placed as to be parallel with its axis, and about ⅛ of an inch from its surface, aid in the charging of the *prime conductor* by facilitating the escape of its *negative* electricity under the inductive influence of the *positively* charged glass cylinder.

139. The Rubber (see figs. 71, 72, and 73) of both cylinder and plate electrifying machines usually consists of a cushion of leather filled with horse-hair and covered with silk. From the upper surface of the front of the cushion a flap of oiled silk, I, proceeds over the top of the cylinder to a convenient distance from the brass points of the prime conductor. It is better that the oiled silk for this purpose should be oiled or varnished on one side only. If oiled on both sides, that turned towards the glass should also be well varnished with two or three coatings of *shell-lac* varnish.

The *rubber* is usually supported from the back by an upright and a cross piece of polished wood. If the *rubber* be supported by a brass cylinder, similar to the *prime conductor* (but without brass points), surmounting an insulating leg of glass, bodies may be charged by means of it with *negative* electricity, on *connecting the prime conductor with the earth.*

140. A Cheap Electric Machine may be easily made by mounting a common black glass wine bottle, in place of the ordinary glass cylinder, on a rough deal stand. The end of the handle should be inserted in the neck of the bottle; the cavity at the bottom of the bottle may be filled up with a mass of wood, in the centre of which is inserted a piece of wire to permit of its rotation. The requisite fittings may be attached to the glass by means of *electric cement* (Art. 142). The *prime conductor* may be constructed of a wooden cylinder (a piece of silk roller) covered with tin-foil, and supported, in the absence of a glass rod, on a stick of *gutta-percha.* A row of common pins (shortened) will serve for the brass points. In the absence of horse-hair the cushion may be stuffed with well-dried wool. In this way, at the cost of a few pence only, any ordinary school-boy may construct an efficient electric machine, with which he can perform all ordinary electrical experiments requiring a machine.

141. The Electric Amalgam more generally used in this country for coating the *rubber* is a compound consisting of one part by weight of *tin,* two of *zinc,* and six of *mercury.* It is best made by melting the tin and zinc together in a crucible, and then adding the mercury, previously heated to a high temperature, to the mixture, stirring till it becomes too cold. To apply the amalgam to the rubber it must first be finely *pulverised,* and then mixed with so much lard or tallow as shall give it the consistence necessary to enable it to adhere. It should then be spread over the silk surface of the *cushion* with a knife, and rubbed over with brown paper or other convenient material, so as to be spread uniformly *along* the middle of the cushion. Another method of applying the amalgam consists in first smearing a thin uniform layer of lard or tallow over the rubber, and then sifting the amalgam, very finely powdered, through a linen sieve upon it, smoothing it down more closely by means of a broad flat knife.

Though the amalgam undoubtedly promotes very considerably the *electrical excitation* of the machine, its precise mode of action is not yet determined. It has been attributed to its chemical union with the oxygen of the atmosphere; but it is again said that other experiments do not strengthen this view.

142. Electric Cement.—A most useful cement, termed *electrical cement*, largely used in the construction of electrical apparatus, is prepared by melting together in a clay pipkin a mixture consisting of five parts by weight of *resin*, one of bees'-wax, one of red ochre, and a little plaster of Paris (about one-eighth of the weight of the bees'-wax used). Care should be taken so that the temperature should not rise much above its melting point, and that the mixture should be kept well stirred while being used.

143. Theory of the Action of the Electrical Machine.—CASE I. When the *prime conductor is insulated* and the *rubber connected* by means of a metallic chain with the *earth*, as in the ordinary working of the machine.

(*a*.) When the neutral glass cylinder or plate is turned the *friction* causes the immediate *separation* of the two electricities.

(*b*.) The *positive* electricity thus separated goes to the *rubbed* glass; the *negative* to the silk *rubber*.

(*c*.) The *positive* electricity of the glass cylinder attracts the *negative* electricity from the insulated *prime conductor*, thus leaving it with an *excess* of *positive* electricity; that is, causing it to become *positively charged*.

(*d*.) The *neutral* electricity of the glass, thus formed by the *union* of its *positive* electricity with the *negative* electricity abstracted *from* the *prime conductor*, undergoes decomposition by *separation* at the next turn of the machine, as shown in *a*.

From this it follows that the surface of the glass cylinder *above* the brass points will be charged with *positive* electricity, while that portion which has *passed*, and therefore lies *below* the brass points, will only contain *neutral* electricity, or, in other words, will not be *electrically excited.*

(*e.*) The *positive* electricity of the *rubbed* glass decomposes an additional quantity of the neutral electricity remaining in the prime conductor, abstracting its *negative* electricity (as shown above in *c*). The negative electricity passing into the *rubber*, already *negatively* charged, is repelled by *its negative* electricity to the earth, or, what is practically the same thing, is attracted by the *positive* electricity of the earth.

If means are not afforded, through the medium of a metal chain or otherwise, for the additional *negative* electricity thus separated to escape to the earth or elsewhere, no further electrical separation can be effected by the machine.

(*f.*) These processes (paragraphs *a, b, c, d, e,*) continue, supposing no electricity to be lost by diffusion, conduction, etc., on the machine being turned, until the *tension* of the *negative* electricity of the rubber and of the *positive* electricity of the prime conductor have become so great as to cause them to *discharge* across the glass cylinder or plate.

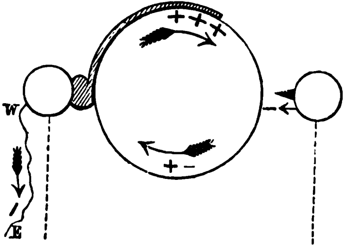


Fig. 74.—SHOWING PASSAGE OF NEGATIVE ELECTRICITY *from* the insulated prime conductor *to* the glass cylinder, *thence to* the rubber, and *from* the rubber *to* the *earth.*—This case is supposed to represent the action of the machine in *ordinary work,* the prime conductor being *insulated* and the rubber in *connection* with the *earth.*

144. CASE II. When the *rubber is insulated* and the *prime conductor is connected with the earth* by a chain.

(1.) The machine behaves as just described in paragraphs (*a*) and (*b*).

(2.) The *positive* electricity of the glass cylinder *attracts*, as in the previous case, *negative* electricity *from* the *prime conductor*, which thus becomes *positive;* but, being now in connection with the earth, immediately attracts (see fig. 75) from it a supply of *negative* electricity *equal* to that of which it was *robbed* by the glass cylinder. Both the glass cylinder and the prime conductor thus *return* to the *neutral* state.

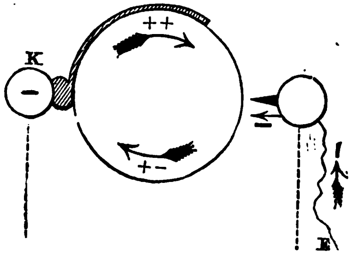


Fig. 75. — Showing Passage of Negative Electricity *from* the *earth*, through the wire (E) to the prime conductor, thence *to* the glass cylinder, and thence to the rubber (K). The rubber in this case is supposed to be *insulated*, and the prime conductor *connected* with the *earth*, as when charging bodies with *negative* electricity.

(3.) The next turn of the glass cylinder *decomposes* its re-formed *neutral electricity*, the *negative* electricity again going to the *rubber*, while the *positive* electricity thus left is again immediately neutralised by the *negative* electricity pumped up, as it were, from the earth by means of the *prime conductor* and connecting wire.

(4.) On continuing to turn the machine all the processes and changes are repeated in the succession described.

(5.) On presenting any insulated *neutral* body to the *negative conductor* attached to the *rubber* it becomes charged *negatively*, by the abstraction of its *positive* electricity, which goes over to the rubber to neutralise its negative electricity.

From the above it follows that when an electrifying machine, whose *prime* or *positive conductor* is connected with the earth, and whose *negative* or *rubber conductor* is insulated, is put into action, it determines a current of *negative* electricity *from* the earth *through* the prime conductor *to* the glass cylinder, and thence *to* the rubber, as shown in fig 75.

145. CASE III. When the *prime conductor* and *rubber* are *connected* by a chain.

(1.) In this case also the machine behaves as in the two former cases, described in paragraphs (*a*) and (*b*), page 108.

(2.) The *positive* electricity of the glass cylinder is immediately *neutralised* by *negative* electricity *drawn* from the *prime conductor.*

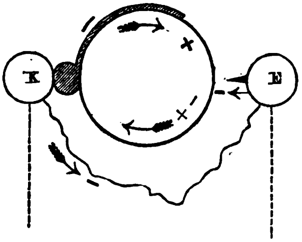


Fig. 76.—SHOWING PASSAGE OF NEGATIVE ELECTRICITY *from* the positive or prime conductor (E) *to* the glass cylinder, thence *to* the rubber (K), and *back* again to the prime conductor.—In this case the *prime conductor* and the *rubber* are supposed to be connected.

(3.) The *positive* electricity of the prime conductor is *instantaneously neutralised* by *negative* electricity *drawn from* the *rubber* now in metallic connection with it.

The restoration of *electric equilibrium* between the rubber and the prime conductor is so rapid and instantaneous that neither of them show any signs of *electric excitement*, consequently they neither yield electric *sparks* nor influence the *gold-leaf electroscope.*

It follows from the above that when an electrifying machine, whose *rubber* is in *metallic connection* with its *prime conductor*, is put into work, it simply determines the passage of a continuous current of *negative* electricity *from* the prime conductor *to* the glass cylinder (see fig. 76), thence to the rubber, and *back* again *to* the prime conductor. In this case the successive *separations* and *neutralizations* of the two electricities are so supposed to be instantaneous, as to be indistinguishable by even our most sensitive electrical tests.

146. Theory of the Process of Charging Insulated Conductors by Communication.—Three theories, each of which, perhaps, in the present state of electrical science, serves equally well to explain the processes by which *insulated conductors* become *electrically excited*, or, in other words, "charged with electricity," by the actual *passage* of electricity from one body to the other, viz.:—

1. *The theory of subtraction*, according to which the charg*ing* body (that is, the body supplied with *excess* of positive or negative electricity) *subtracts* the *opposite* kind of electricity to its own from the body under process of being charg*ed*, thus leaving the latter charg*ed* with a *surplus* of the same kind of electricity as that of the charg*ing* body.

2. *The theory of addition.*—According to this theory a body becomes electrified by receiving directly from the electrically excited or charg*ing* body, as the prime conductor of an electrical machine, a portion of that kind of electricity which it contained in *excess*.

3. *The theory of addition and subtraction.*—According to this theory, which combines the two former theories, a body becomes charged with a given electricity, both by the *abstraction* of the *opposite* and the *addition* of the *same* kind of electricity. Thus the prime conductor of an electrical machine, as ordinarily worked, would become *positively* charged by the simultaneous abstraction of a portion of its *negative* electricity, by the *inductive* action of the positive electricity of the *rubbed* glass plate or cylinder, and by the escape of a portion of the *positive* electricity from the *rubbed* glass to the conductor; or, in other words, the conductor becomes *charged* with *positive* electricity, partly by being *robbed* of its *negative* electri-

city, which passes over *to* the positive glass, and partly by its being *endowed* with *positive* electricity, which passes *from* the excited glass *to* the conductor.

In all cases a body becomes charged *positively* or *negatively* in proportion as it is *deficient* of an equal quantity of the *opposite* or *dissimilar* kind of electricity: that is, a body is not positively or negatively charged according to the *absolute* quantity of *positive* or *negative* electricity it possesses, but in the degree to which it possesses a *surplus* quantity of the one kind over that of the *opposite* kind of electricity.

As the *subtraction* theory of the mode of *electrifying* bodies explains all known electrical phenomena as thoroughly, and, perhaps, even more simply and briefly than either of the other theories, the writer of this little book has throughout adopted it exclusively. The student, however, who has fully mastered it in its application to the various electrical phenomena, will have no difficulty whatever in applying either the *addition*, or the *addition* and *subtraction* theory to all cases of charg*ing* by electrical machines, or by electrically charg*ed* bodies. The student should also see clearly that there can be no practical difference between a *negative* current's *leaving* and a *positive* current's *entering* a neutral body. It would also, perhaps, be as well that the student should always recollect that probably in no case of electrical excitement does a fluid or other substance really *leave* the bodies under experiment—*electricity*, like *heat*, being much more probably a *mode of motion* than a specific *substance*.

147. The Ordinary Plate Electrical Machine differs from the cylindrical machine, previously described, chiefly in the substitution of a flat circular glass plate for the glass cylinder. The substitution of the *circular plate* for the cylinder necessitates certain minor alterations of construction, which will be readily understood on reference to figs. 77, 78, 79. The principles of the action of the *plate* machine are precisely similar to those of the *cylindrical* machine, previously explained. The former is more convenient for the purpose of collecting *negative* electricity from the *rubbers,* especially when, as is usually the case with the best machines, the supporting pillars (CC) are made of *glass* in place of *baked wood.*

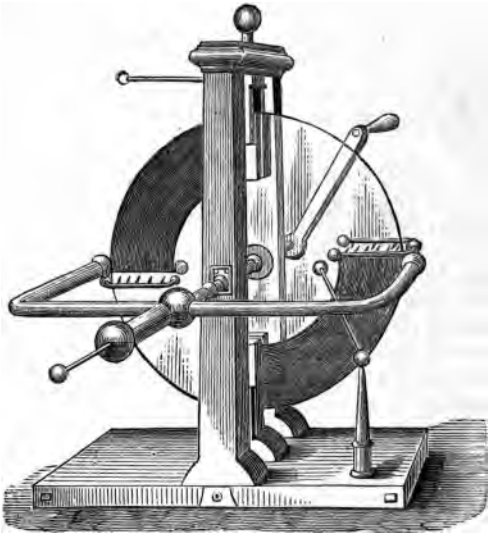


Fig. 77.—Common Plate Electrical Machine.

The most convenient plate machines in general use vary from 12 to 30 inches in diameter. The latter, when in good condition, should yield a spark from 4 to 6 inches long from the prime conductor. Great care is required in warming them before the fire, otherwise the plate is apt to become unequally heated, and to crack. As a rule plate machines are more liable to get broken or injured in use than cylindrical ones.

Plate machines, as a rule, present a *greater distance* between the rubber and the prime conductor than cylindrical electrical machines of the same general size—the former consequently generate electricity of higher *intensity* than the latter.

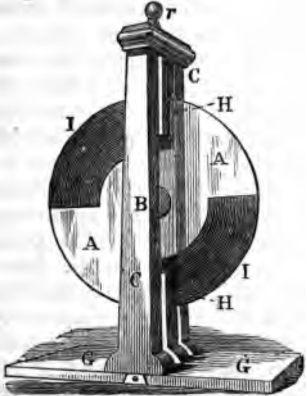


Fig. 78. — Parts of Plate Machine.

AA, Circular glass plate.
HH, Two pairs of rubbers.
II, Silk flaps attached to rubbers.
r, Brass knob for connecting rubber with earth.
GG, Wooden base of machine.

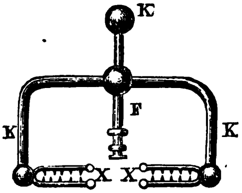


Fig. 79.—Prime Conductor of Plate Machine.

F, Glass support.
KKK, Conductor.
XX, Combs of conductor.

148.* The Winter's Plate Electrical Machine, which, differing somewhat in details of construction from the ordinary plate machine, possesses special qualities of excellence, more especially the power of giving very long sparks—sparks three and four times the length of those given by the ordinary plate machine—is now, though a comparatively modern instrument, found in the shop windows of the leading philosophical instrument makers of most large towns. The Winter's plate

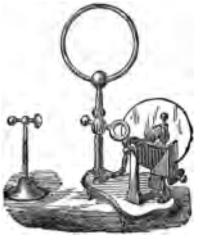


Fig. 80. — A Winter's Electrical Machine.

machine has but *one* pair of rubbers and oiled silk flaps, which therefore permits their being placed at a *greater distance* from the *positive conductor* than those of ordinary plate machines which have *two* pairs of rubbers. The glass plate is mounted on a *glass* axis, and *wooden* fittings are substituted for *brass* or *metallic* ones wherever possible, by which means a considerable loss of electricity is avoided over that of the ordinary machine. The *combs* of the prime conductor are contained within grooves in two wooden rings connected with the ball of the prime conductor, and placed one on each side of the revolving plate. At the bottom of each groove is a strip of tin-foil, which receives the electricity collected by the points. Into the top of the large brass ball forming the prime conductor of the machine is inserted by a suitable foot, when very long sparks are required, a very large ring, 3 to 4 feet in diameter, of peculiar construction. A machine of 24 inches diameter, in feeble working condition, capable of giving a 2-inch spark only, on being fitted with the large ring, immediately gave a 14-inch spark.

The *Winter's ring* consists of a core of thick brass or iron wire, surrounded and completely covered by an external ring of well-baked polished wood: the internal metallic ring terminates in a stem by which it is fitted into an aperture in the top of the prime conductor.

An apparatus, termed the "spark drawer," consisting of a wooden pillar and foot, supporting a broad flattish brass ball, is also used in drawing the long sparks from this machine.

CHAPTER IX.

DISTRIBUTION AND TENSION OF ELECTRICITY—ACTION OF POINTS.

149. Free Statical Electricity distributes itself over and Resides on the Outside of Insulated Conductors.—

Free electricity in all cases except (*a*), in the condition of an *electric current;* and (*b*), when under the *inductive* influence of an *internal insulated* electrified body, distributes itself over and takes up its *residence* exclusively in the *external surface* of an *insulated conductor.*

This result is brought about by the *self-repulsive* power of the electric fluid, aided by the conducting power of the electrified body. It has been *mathematically* demonstrated that a *self-repulsive* fluid, liberated from the action of gravity, whose particles repelled each other with a *force* varying *inversely* as the squares of their distances from each other, would thus tend to distribute itself in the form of a hollow shell over the interior walls of the containing vessel.

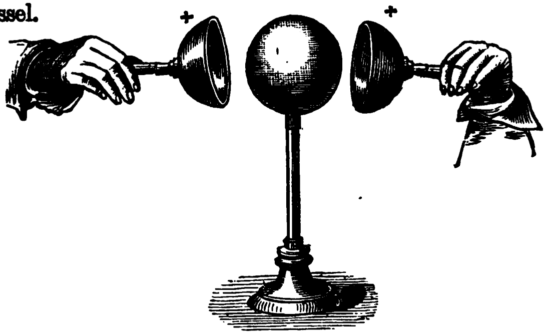


Fig. 81.—Biot's Experiment, showing tendency of electricity in insulated ball to escape to outer surface of insulated hemispherical caps.

Experiment I. (known as Biot's Experiment). — Charge a large metal ball, properly *insulated* on a glass stand, with either *positive* or *negative* electricity by means of the electrifying machine. Then bring two hollow hemispherical brass caps, *un*-electrified, but held by glass *insulating* handles (as shown in fig. 82), into contact with the *electrified* ball. On removing the caps —taking care that they do not in the course of removal again touch the ball — they will be found, if tested by the electric pendulum or gold-leaf electroscope, to be charged with the electricity originally contained in the ball. The ball itself, on being similarly tested, will be found to have lost all trace of electricity, having become quite neutral.

This experiment is, however, much more difficult to perform than the description would imply.

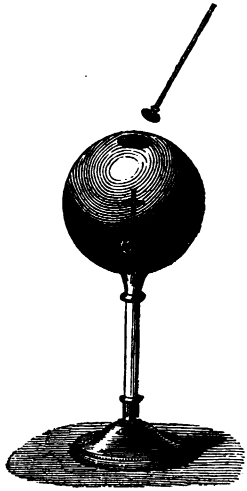


Fig. 82.—Showing mode of testing interior of HOLLOW ELECTRIFIED BALL, by means of PROOF-PLANE.

EXPERIMENT II.—Charge an insulated *hollow* brass ball containing an aperture sufficiently large for the introduction of the *proof-plane* or *carrier-ball* into its interior. (*a*), Pass the *proof-plane* through the aperture into contact with its interior wall; remove and *test* by means of *gold-leaf* or *torsion* electrometer. No effect is produced, proving its interior to contain *no* free electricity. (*b*), Bring the *proof-plane* or carrier-ball into contact with its *exterior*, and test as before: the gold leaves immediately *diverge*, or the needle of the torsion electrometer is immediately *deflected*. The electricity therefore *resides* in the *outer surface* of the ball.

EXPERIMENT III.— Repeat the experiment with a basket of *wire* or *wire gauze*, supporting the cage work on an *insulating table*, or by means of the glass handle (G, fig. 83). The electricity will still be found resident on its outer surface.

EXPERIMENT IV.—Place a metal ball, or any good conductor, in the metallic cage (H B N, fig. 83), and hold it, by means of the glass handle (G), to the prime conductor of the machine at work. It will be found impossible to *charge* the *contained* body, though the *outside* of the wire cage, when tested, may be shown to be *powerfully charged.* In this case the contained ball must be *smaller* than the interior of the vessel, so as to lie *below* its upper edge.

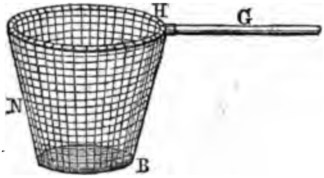


Fig. 83. — WIRE BASKET, H B N; with GLASS HANDLE, G.

EXPERIMENT V. — 1. Charge an *insulated* brass ball (A) with electricity, and test the tension of the same by means of the *proof-plane* and *torsion* or Thomson's *quadrant electrometer*.

2. Bring a *solid* brass ball (B), in *size* and other respects exactly similar to the *first*, into *contact* with the first ball. The second ball is to be *insulated*, but not electrified. *After* being brought into *contact* with the first, it will be found, on carefully *testing* with the *torsion* or Thomson's *quadrant electrometer*, that the second ball has removed exactly one-*half* of its charge from the first ball—the charge of the latter dividing itself *equally* between the two balls.

3. Repeat the above experiment, now using in place of the *solid* a *hollow* brass ball, insulated and in every other respect similar to the *solid* one. On bringing the charged and *un*charged balls into *contact*, as before, the *hollow* ball will be found to have taken up the same charge as the *solid* one; thus showing that the *exterior* only has to do with the taking of the charge, or, in other words, that the electric charge must reside in the *outer* surface, and not in the *interior* of the solid.

EXPERIMENT VI. — (*a.*) Let the insulated brass ball (A) be charged with a *unit* quantity of electricity

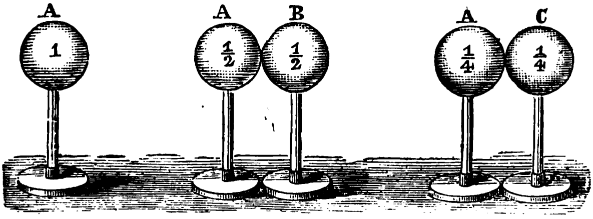


Fig. 84.—SHOWING DIVISION OF ELECTRIC CHARGE.

(*b.*) Bring the electrified ball (A) into contact with a precisely similar *un*electrified ball (B), they will divide the electric charge equally between them, each retaining *half* of the former charge of A.

(*c.*) Now bring either A or B into contact, as in the last case, with a precisely similar *un*electrified ball (C), it will divide its charge equally, A and C each retaining now *one-fourth* of the original charge of A.

This *law* of division was first proved by Coulomb, who first established the fact by means of his *torsion electrometer*, that the *intensity* of a given charge *varied* with the *surface* over which it was distributed.

EXPERIMENT VII.—Place a wire cover (as a meat cover) over a live mouse, bird, or other animal: a gold-leaf electroscope and some inflammable matter may also be placed under the cover.

Support the whole on a stool with glass legs, and then charge by means of a powerful electrical machine. Though streams of long sparks may be drawn from the cover, the mouse and other objects below are incapable of becoming electrified—the electricity distributing itself entirely over the *outer surface* of the *wire cover.*

The late Professor Faraday, to whose brilliant investigations in electricity the world is so largely indebted, constructed a cubical room, each side of which was about 12 feet square, the outside of which was covered with tin-foil and copper wire. The whole was insulated from the earth, and powerfully charged with electricity, so that it glanced from its exterior in streams of sparks. While this large box or room was thus so powerfully charged with electricity, Faraday himself spent some time experimenting in its interior, applying all the usual testing instruments, including gold-leaf electroscopes, electrometers, lighted candles, etc., without obtaining the slightest indications of the electrically charged condition of its exterior walls. Professor Faraday, also, while lecturing, and when using powerful electric machines, protected his delicate gold-leaf and other electrometers by covering them up with loose cotton nets. The electricity, which would otherwise have destroyed them, was thus confined to the surrounding network.

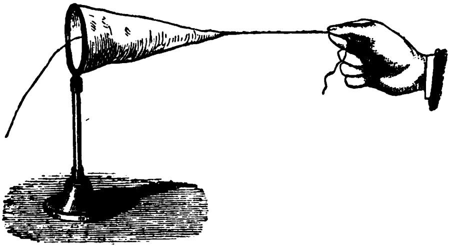


Fig. 85.—FARADAY'S BUTTERFLY NET EXPERIMENT.

150. Faraday's Butterfly Net consists of a small conical muslin, linen, or gauze bag, 4 to 6 inches in diameter, and 9 or 10 inches long, attached to the top of a glass rod and stand by a brass ring. The bag may be turned inside out in either direction by means of two threads of *silk* attached, one to the *inner* and the other to the *outer* apex of the bag.

EXPERIMENT VIII.—(*a*), Electrify the bag in the position shown in the figure. (*b*), Test the *inside* of the *electrically excited* bag by means of the proof-plane and a sensitive gold-leaf electroscope. The electroscope will *not* be affected, consequently its inner surface is *neutral.* (*c*), Test its *outer* surface in a similar manner. On bringing the *proof-plane* to the electroscope, the gold leaves will immediately *diverge.* The electricity therefore *resided* on its outer surface. (*d*), Turn the bag inside out, taking care only to touch the inside *silken non-conducting* thread. On *testing,* as before, the electricity will now be found to have *changed sides* also, having *left* the side in which it previously resided, when that side was *outward,* and *entered* that which formerly was the *in*side, has now become the *out*side, of the bag. If the bag be previously well warmed, and care be taken not to touch it, the experiment may be repeated many times in succession.

151. Effect of Increase of Surface on Electric Charge. —If the *surface* of an *insulated electrically excited* conductor be *increased* (the quantity of electricity in it remaining the same), its resident electricity will diffuse itself over its entire (increased) surface, and consequently become weaker, that is, less *intense,* in the manifestation of its *attractive* and *repulsive* powers, and in its tendency to *escape.*

In this case the *electric density*. or, as it is sometimes more objectionably described, the *thickness of the electrical stratum,* is *diminished* in the ratio in which the electric surface is increased.

Fig. 86 represents a piece of lecture table apparatus, designed to illustrate by experiment the relation between *surface* and *quantity* of electricity. It consists of a revolving metallic cylinder, to the right hand of which is attached an *insulating* handle for rotating the cylinder; and to the left hand, in electric communication with the cylinder, is placed a *Henley's quadrant electrometer.* On the middle of the cylinder is wound a broad sheet of *tin-foil,* capable of being *un*wound by means of a *silk* thread. The metallic cylinder, with roll of tin-foil, is supported and *insulated* by means of two *glass* pillars inserted in a suitable wooden stand, with oval opening, to permit of the *unrolling* of the tin-foil.

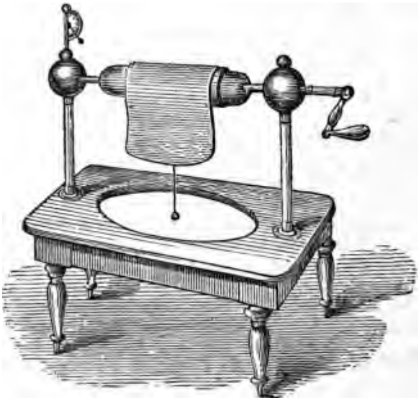


Fig. 86.—Lecture Table Apparatus for Illustrating Relation of ELECTRIC DENSITY to ELECTRIC QUANTITY and SURFACE.

EXPERIMENT IX.—(*a.*), Charge the metallic cylinder (fig. 86) and roll of tin-foil with electricity by means of the machine (the apparatus having been previously well warmed and dusted). As the apparatus becomes charged the pith ball of the electrometer on the left hand will gradually *rise*, until the charge attains its *maximum* tension and density.

(*b.*) Unroll the *tin-foil* by means of the *silk thread*. As the tin-foil is unwound the electricity, of comparatively high tension, spreads over the enlarging *conducting* surface, the *pith ball* and index of the electrometer gradually falling because of the diminished *repulsive* force of the electricity, until the tin-foil is entirely unrolled.

(*c.*) Rewind the *tin-foil* by the handle. As the surface becomes smaller the *pith ball* again *rises*, until it has nearly attained its former position.

EXPERIMENT X. — The following is a much *cheaper*, though rougher, form of this experiment:—(*a.*) Take a stick of glass or sealing-wax (R R, fig. 87), to which attach, by means of sealing-wax or shell-lac varnish, a *sheet* of *tin-foil* (F); connect the lower end of the tin-foil by means of a thin *wire* to the cap of a *pith ball*, or a not very sensitive *gold-leaf electroscope*.

(*b.*) **Charge the unrolled sheet with electricity by means of the machine**—the gold leaves will immediately *diverge.*

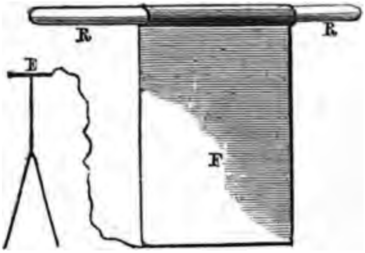


Fig. 87.—Simple Form of Apparatus for Illustrating Electric Density.

(*c.*) Holding the cylinder by its two extremities, *roll* up the *tin-foil* on the cylinder, taking care not to touch the foil with a conductor. The gold leaves will *diverge* still more as the surface of the *tin-foil* is reduced by its being rolled up.

Experiment XI. — 1. Take a metallic chain (*a*), to one end of which is tied a piece of *silk* thread (*b*), and place this in a tin vessel (*c*), supported on an insulating table with glass leg (*d*); to the outside of the tin vessel attach two pith balls (*f*), suspended by cotton threads from the metallic arm (*e*).

2. Charge the *insulated* vessel and chain by means of the electrical machine, taking care to leave the *silk* thread hanging over the side of the vessel. As the vessel becomes electrically charged, the *pith balls* gradually diverge, until they attain a maximum *divergence.*

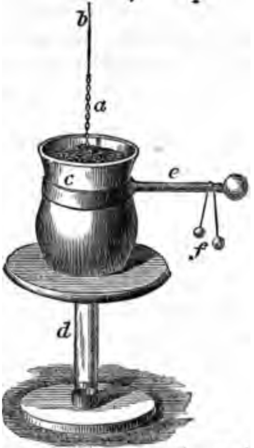


Fig. 88.—Metallic Chain Apparatus for Illustrating Electric Density.

3. *Raise* the chain gradually out of the vessel by means of the *silk* thread. As the chain is raised, the conducting surface over which the electricity diffuses itself is increased, the *divergence* of the leaves is therefore lessened, until the whole of the chain,

except the end in *contact* with the vessel, is raised, when the *pith balls* sink down to their *minimum* of divergence.

4. Gradually lower the chain below the edge of the vessel, as the chain returns within the vessel the *pith balls* again *diverge* more widely until they have nearly attained their original degree of *divergence.*

152. Effect of Decrease of Surface on Electric Charge.—The experiments just described also show that if the *surface* of an *insulated conductor* be *diminished* (the quantity of electricity in it remaining the same), its resident electricity will become concentrated on the *smaller* surface, thus consequently becoming *more intense,* and manifesting *greater* powers of *attraction* and *repulsion,* and a greater tendency to *escape.*

153. Electric Density.—By *electric density* is meant the quantity of electricity spread over a given *unit* of *area* or surface. If we *double* the *quantity* of electricity contained on any given *unit* of surface of a conductor, we *double* the *electric density;* if we *halve* that quantity, we reduce its *electric density* to one-*half.*

The term *electric density* expresses the *quantity* of electricity existing at any given time on a given *unit* of surface or area. Let $Q =$ the *quantity* of electricity on any given *unit* of *area,* and let $a =$ that *unit,* then $\frac{Q}{a} =$ the *electric density* in that place.

The collection of electricity on conducting surfaces has been compared with that of a fluid, say water, collected on a given area of surface. If the *same* quantity of water were collected on one-*half* the supporting surface, it is quite clear its depth would be *twice* as great; if on *one-third* the surface, *three* times as great, and so on. On this analogy, in some respects useful though probably false, the term *thickness of electrical stratum* or *layer* has been used as synonymous with *electric density.*

The term *electric density* is now used with greater accuracy by modern electricians, to signify the *quantity* of electricity on a *square centimetre* of surface of an electrically excited conductor.

154. Electric Tension.—By *electric tension* is meant the tendency or the degree of force with which the electricity, accumulated on any conducting surface, tends to *escape.*

Electric tension is frequently confounded, especially by the young student, with *electric density;* but though in general we have greater *tension* where we have greater *density,* yet they are essentially different, the *tension* at a given point being, according to Laplace, *proportional* to the *square of the electric density. Electric tension* has been defined as "the result of difference of *electric potential.*" (See "Electric Potential.")

155. The Distribution of Free Electricity on the Outside of an Insulated Conductor depends on its Shape.—*A sphere*—If an electrified insulated brass *sphere* be examined by means of the *proof-plane* and a sensitive *gold-leaf,* or still better, a *torsion* electrometer (as described in Art. 156, see also fig. 91), the gold leaves will be found to *diverge* equally, or the *torsion needle* to be *deflected* equally, from whatever part of the *sphere* the charge be collected by the *proof-plane.* The *electric density* is therefore the same at all points of the surface of an insulated electrified *sphere,* provided, of course, it be at such a distance from surrounding objects as *not* to be appreciably affected *inductively* by their influence. In such a sphere, therefore, the electricity distributes itself *symmetrically* over the entire surface. (See A, fig. 89, in which the *electric density* is indicated by the thickness intervening between the outer dotted and the inner black line denoting the section of the electrified body.)

A cylinder—The *electric density* of a long cylinder (B, fig. 89) with rounded ends is greatest (as shown by the *divergence* of the *pith balls* and the depth from the dotted line), at first suddenly and then gradually diminishing from the ends to the middle of the cylinder.

A cone or *ellipsoid*—The electric density is *greatest* at its most *pointed* extremity, becoming *least,* as shown by the dotted lines and pith balls, at some point between the two extremities, but nearer the thicker end (see C, fig. 89).

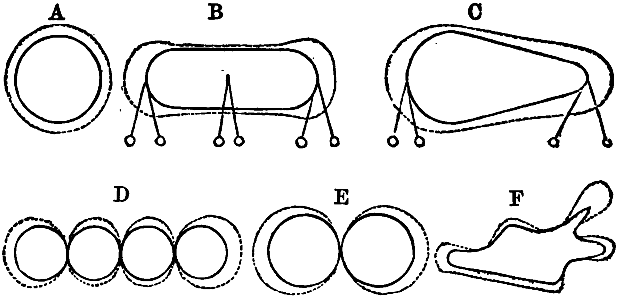


Fig. 89.—SHOWING ELECTRIC DENSITY OF AN ELECTRIFIED SPHERE A—a cylinder B—a conical ellipsoid C—spheres in contact D and E—of an irregular figure F, containing deep cavities and high projections.

156.* Coulomb's Mode of Testing the Distribution of Electricity on the Surface of Bodies.—Bring the *proof-plane*, after discharging any free electricity it may

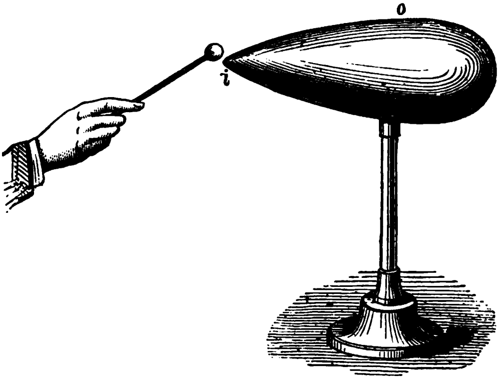


Fig. 90.—SHOWING MODE OF TESTING ELECTRIC DENSITY ON SURFACE OF ELLIPSOID OR OTHER BODIES BY MEANS OF PROOF-PLANE.

have contained, into contact with any point (say *o* of the ellipsoid, as shown in fig. 90).—Then test proof-plane by means of *gold-leaf electroscope* or torsion electrometer. —Repeat the experiment with electricity obtained, say from point *i*.—Note the *greater divergence* or *torsion*, as it may be, in the latter case.

157. The greater intensity of the electricity at the point *i*, as compared with that at point *o* (fig. 90) of the ellipsoid, may be shown more easily, but with less accuracy, by bringing successively the *proof-plane*, charged with electricity, from the respective points (*o* and *i*) into contact with the disc of a sensitive gold-leaf electroscope. After each contact of the *proof-plane* the gold leaves will diverge, but they will diverge to a greater distance with the electricity derived from the *apex* (*i*), or points near the apex, as compared with that derived from points nearer the flatter portion (*o*) of the ellipsoid.

158. Dispersive Action of Points (Electrical Aura). —Points and sharp edges counteract or neutralise the action of *insulators* by concentrating the electricity at their terminals, until its *density* becomes so great as to cause it to *discharge* itself into the atmosphere. Points therefore prevent the accumulation of electricity.

If the brass ball (D, fig. 91) be placed on the point (C), the electric density on the surface of the prime conductor immediately rises considerably, as indicated by the Henley's quadrant electrometer, or as tested by the proof-plane and electroscope; on removing the ball by the silk thread (*e*), its electric density immediately falls to *zero*, or thereabouts.

When the prime conductor or other electrified body terminates in a point, the electricity escapes from the point into the air—the particles of the air becoming thus charged with electricity of the same kind as that of the point, are immediately repelled by each other and by the point: other particles rushing in to supply their places become similarly *electrified* and self-repellent, and thus produce a current of air or *wind* termed the *electrical aura.* (See Arts. 186, 187.)

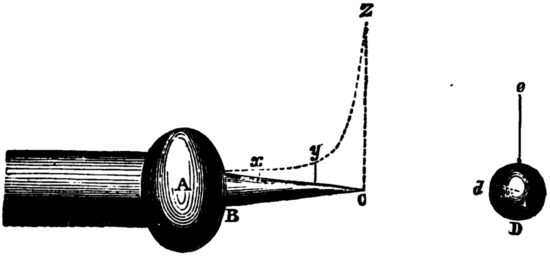


Fig. 91.—SHOWING ELECTRIC DENSITY AT POINTS.

A, Prime conductor.
BC, Metallic point.
xyz, Curve, the depth measured from which to the various points of the wire shows the relative electric densities at those parts of the surface.
D, Brass ball fitting on to point C by aperture *d*.
e, Silk thread for removing ball from point (C).

159. Exception to Law of Distribution of Statical Electricity on Outside Surface of Electrified Bodies.—When an *electrified body* is placed in the interior of a hollow vessel, but so as *not* to touch its walls, the electricity of the latter (decomposed by the inductive influence of the electrified ball) no longer distributes itself exclusively over the *exterior* surface of the vessel, but becomes diffused over both its *exterior* and *interior* surfaces. (See "Ice Pail Experiments," fig. 61.)

In this case the *positive* electricity in the ball (B) acts *inductively* upon the *neutral* electricity in the metallic vessel (V), *attracting* the *negative* electricity to its *interior*, and *repelling* the *positive* electricity to its *exterior* surface, thus *decomposing* the *neutral* into its constituent fluids.

EXPERIMENT.—Suspend by a *silk* thread the ball (*s*, fig. 92), charged with *positive* electricity in the middle of an *un*electrified metallic vessel (C) mounted on a *glass* leg.

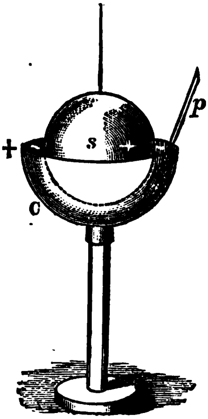


Fig. 92.—SHOWING EXCEPTION UNDER INDUCTIVE INFLUENCE TO DISTRIBUTION OF STATICAL ELECTRICITY ON EXTERIOR SURFACE ONLY.

C, Metallic vessel on *glass* leg
s, Metallic ball electrified *positively*, and suspended so as neither to touch interior nor allow its electricity to escape to the walls of the hollow vessel.
p, Proof-plane.

If the *interior* surface of the vessel be now tested by means of the *proof-plane* (*p*) and gold-leaf electroscope, it will be found to be *electrically excited* with a charge of *negative* electricity. If the *exterior* surface be similarly tested, it will be found to be charged with *positive* electricity.

160. Theory of the Action of Points.—(*a.*) A *point* may be practically regarded as consisting of a *succession* of balls of gradually diminishing size, in contact with each other, as shown (A, fig. 93).

(*b.*) Coulomb has shown that if a large ball be electrified to a given intensity, that is, so that it shall contain a given *quantity* of electricity to the square inch; and also a second much smaller ball be taken and electrified to the *same* degree of *intensity;* and the two electrified balls be brought into contact with each other, the electricity will, though previously of the *same* density in each ball, so *re-distribute* itself as to be of much *greater density* at that point of the line passing through the centres and point of contact of the two balls, which is outside the *smaller* ball, than at the corresponding point outside the *larger* ball.

(*c.*) Let B, fig. 93, represent such a decreasing series of balls, then the thickness of the shading about the terminal balls of the series may be taken as roughly indicating the relative electric density at the two ends of the wire point.

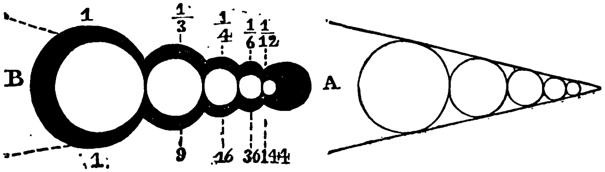


Fig. 93.—Illustrates Theory of the Action of Points considered as a Succession of Gradually Diminishing Spheres.

A, Series of gradually diminishing balls forming point.
B, Shows (roughly) increasing electric *density* on smaller spheres towards end of point.

In the above case, supposing the diameter of the *largest* ball be taken as *unity,* and that of the second as $\frac{1}{3}$, of the third as $\frac{1}{4}$, of the fourth as $\frac{1}{6}$, and the fifth as $\frac{1}{12}$ of its diameter, as shown by the upper series of numbers, then the relative intensity of the electricity of the various points would, as shown by the lower numbers, be 144, 36, 16, and 9 times the electric density of that on the outside of the largest ball.

CHAPTER X.

CONDENSERS — THE LEYDEN BATTERY — EXPERIMENTS: PHYSIOLOGICAL, MECHANICAL, PHYSICAL, AND CHEMICAL, WITH THE ELECTRIFYING MACHINE.

161. A Condenser or Accumulator is an electrical instrument by which, through the agency of *induction*, we are enabled, by means of a second conductor, to *augment* the quantity of electricity capable of being stored up on the surface of the first, an *insulated* conductor.

Every *condenser* consists of two conductors, *separated* by an *insulator* or *dielectric*. The one conductor must be *insulated*, the other in connection with the *earth*, or some very large *neutral* body. The best known forms of condenser are the Leyden jar and the Franklin's pane.

162. Æpinus's Condenser is the most convenient form of apparatus for illustrating the general principles and action of the electric condenser. It consists (see fig. 94) of a central removable disc (C) of glass, shell-lac, or other *dielectric*, supported on a glass leg, and two brass discs (A, B) supported on glass pillars, movable along a graduated bar attached to the wooden base of the apparatus. The disc A, attached to the prime conductor of the machine, is termed the *collecting plate;* the disc B, which, when the instrument is in use, is connected with the ground, is termed the *condensing plate.*

163. Theory of the Condenser.—The condenser enables the *collecting* plate to take up a greater quantity of electricity from a given source, by *binding* or rendering *latent* a portion of its charge, by which it is enabled to take up an *additional charge* not only to that it has *already* taken up from the electrified body, but in *excess* of what it would otherwise have taken from that body, but for the *aid* of the *condenser.* Thus let a *neutral* body, A, be brought into *contact* with an *electrified* body, B, the electricity from B will flow into A until the *electric potential* and consequently the tension of the electricity of the two balls is equal; that is, the electricity will flow from the *electrified* into the *un*electrified ball until the *repulsive* tendency to escape from the previously *neutral* ball *equals* the *repulsive force* with which the electricity is *driven from* the *electrified* ball. Now it is evident that if a portion of the electricity received by A be *bound*, that is, be practically and temporarily deprived of its power of resisting the entrance of electricity from B, it will take an additional charge; also, that if a portion of the additional charge received be bound, it will

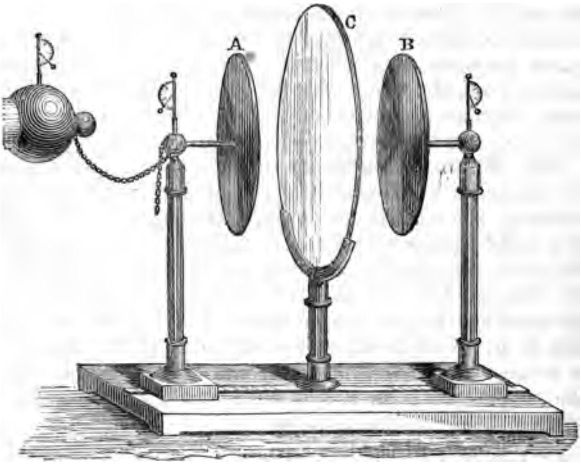


Fig. 94.—ÆPINUS'S CONDENSER.

A, Circular metal disc *insulated* by glass leg, but connected with prime conductor of electrical machine by chain.
C, Circular dielectric (glass) disc.
B, Circular metal disc on glass leg, to be connected with *earth* by *metallic* chain when the condenser is put into action.

The prime conductor and metal discs are in this case each supplied with a Henley's quadrant electrometer. The metallic discs are also capable of being fixed at regulated distances by means of the bar and scale at the base of the instrument.

again take up an additional share of the charge of B, and so on for each additional quantity thus *bound.* This then, theoretically, is the result of the *inductive* action of the *condensing* plate.

164. Free Electricity.—When electricity, either *positive* or *negative,* exists, *un*combined with its *opposite* kind of electricity, *and* is capable of exerting to a marked and obvious degree its *attractive* and *repulsive* powers *indifferently* on surrounding bodies, it is said to be *free.*

165. Bound, Captive, Disguised, Dissimulated, or **Latent Electricity.** — When either kind of electricity exists *un*combined with its *opposite* kind, but is *incapable* of *attracting* or *repelling,* or manifesting its inductive power on *bodies in general,* in consequence of the special *inductive* action of an *adjacent store* of the *opposite* electricity acting through the medium of a dielectric, it is said to be *bound,* etc.

All *un*combined electricity, which behaves towards *objects in general* as though it were *neutral* or *absent,* is therefore described as *bound* or *latent* electricity. The terms *free* and *bound,* though open to *objection* on *theoretical* grounds, are still, in the present state of the literature and nomenclature of the science, most convenient forms of expression.

166. Experimental Illustration of the Nature of Free and Bound Electricity (see fig. 95).

(1.) Take two brass (or card covered with tin-foil) discs, insulated on glass legs; connect each by means of a wire with the cap of a gold-leaf electroscope, keeping the metal discs at some distance from each other; charge the one disc with *positive* and the other with *negative* electricity—the gold leaves of each of the electroscopes will now *diverge.*

(2.) Now bring *gradually* the two discs nearer together; as the discs *approach* each other the gold leaves will gradually collapse, until at last, when the electrified discs are nearly in contact, they will almost have ceased to diverge. This is due to the *inductive* influence which the two *differently electrified* discs exert on each other. As the distance between the two discs becomes *less,* the two *dissimilar* electricities attract each other with greater force, so as to cause the electricities of each disc and electrometer to collect on the *front* faces of the discs, consequently leaving *less* electricity in the gold leaves of each electrometer, which thus more or less *collapse.* The electricities thus removed from the gold leaves and caps of the electrometer by the mutual attraction of the electricities of the two discs are said to be *bound, latent,* etc.

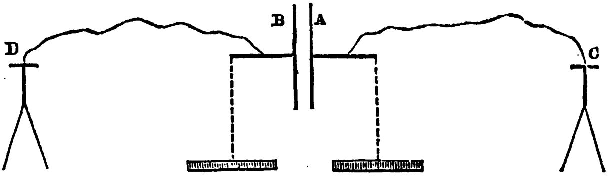


Fig. 95.—EXPERIMENT ILLUSTRATING FREE AND BOUND ELECTRICITY.

A B, Two movable metallic discs (charged with opposite electricities) on glass legs.

C D, Two gold-leaf electroscopes connected with A and B by metallic wires.

(3.) On again slowly separating the discs, the electricities liberated by the reduced *induction* of the two discs gradually return to the gold leaves, which concurrently increase in divergence until they again attain their *maximum* divergence. The electricity thus liberated is described as *free* electricity.

See also D, fig. 52, where the *negative* electricity of the *electrometer* is bound by the *positive* electricity of the glass rod, the removal of which immediately liberates *free* electricity from the cap of the electrometer E (same fig.), which causes the gold leaves to *diverge.* In the experiment above described the insulated metal discs, separated by a layer of *air,* practically form a *condenser,* and either of the discs will, when close together, and when consequently some of its electricity is *bound,* take an *additional* quantity of electricity from a *feebly* charged body, which either of them would have refused when the two were farther apart, and more of their electricity was in a *free* state. It is thus that, by the addition of a *condensing* plate, the gold-leaf electroscope is rendered far more *sensitive.*

167. Experiments with the Æpinus's Electrical Condenser (see fig. 94).

I. (1.) Connect the metal plate (A) with the prime conductor of the electrical machine. Place the two plates (A and B) at *equal* distances from the glass plate (C). Put the machine into work, — the *pith balls* of the *three* quadrant electrometers will immediately *rise*, because charged with *positive electricity*. The electrometers on the *prime conductor* and the first disc (A) and its supporting arm become charged with *positive* electricity by direct *communication*. The *back* of the *second* disc (B), together with its supporting arm, will become charged with positive electricity by the *inductive action* of the disc (A), its *front* becoming charged with *negative* electricity.

(2.) Move the two discs farther away, the quadrant electrometer on B will fall. Bring the discs *nearer*—the *nearer* they are brought together the more the pith ball and index of each of their electrometers will *rise*.

II. (1.) The metallic plates (A and B) being brought close up as before, electrify; the pith balls will stand out as before (that of B only standing off at a *greater* distance). Now touch B with the finger, or, what amounts to the same thing, connect it with the earth by means of a brass chain, an electric *spark* passes, and the pith ball of its electrometer immediately falls to *zero*, because of the escape of all its *free positive* electricity.

(2.) Now, *first*, disconnect B with the earth, *then* disconnect A with the machine (removing the chain by means of a glass rod). No change is produced. The index of the electrometer of disc B remaining at zero, and that of A as before.

(3.) Touch the disc A with the finger; the whole of its *free* electricity, that is, of the electricity it would have received from the prime conductor, without the aid of the *condensing* plate, now escapes, and its pith ball index falls to *zero;* but, simultaneously, that of B rises from its charge of *free* negative electricity. All the electricity which now remains in A is *bound* or *dissimulated*, and was obtained from the prime conductor *by* the *inductive action* of the *condensing* plate B.

(4.) Touch the disc B with the finger, and its *free negative* electricity escapes, its electrometer index simultaneously falling to *zero*, while that of A rises from the setting *free* of a portion of its store of *bound* electricity.

(5.) Repeat all the above operations. In this way 200 or 300 sparks may be *alternately* drawn from each disc, the electrometer indexes also alternately rising and falling on each discharge.

This mode of discharging the condenser is termed the *slow discharge*, and all the electricity thus discharged from A, except that discharged by the first touch of the finger, was previously *stored* up through the *inductive* agency of the *condensing* plate B, in connection with the earth, on the *collecting* plate in connection with the prime conductor.

168. Effect of Interposing Screens of Different Dielectrics.—If while the condenser is in connection with the electrical machine, the screen of glass be replaced by one of resin, sealing-wax, or shell-lac, the charge capable of being accumulated on the plates of the condenser will be found to vary greatly. And that *dielectric* screen which condenses the greatest electric charge is said to have the highest *specific inductive capacity.*

169. Limits of the Action of Condensers.—The quantity of electricity which can be stored up on the surface of the plates of a condenser is limited:—(1) By the *tension* of the electricity of the prime conductor; (2) by the *distance* between the two plates, or, in other words, by the *thickness* of the *intervening dielectric;* (3) by the *cohesive* power of the *dielectric,* or the power with which it resists *fracture;* (4) upon the *specific inductive capacity* of the *dielectric* used.

170.* Volta's Condensing Electroscope consists of an ordinary gold-leaf electroscope, to the top of which, in place of the ordinary knob or small disc, is attached a condenser, consisting of a collecting plate and an upper movable condensing plate with glass handle. The fronts of the two plates are covered with thick coatings of *shell-lac varnish.* The *condensing* and *collecting* plates are thus separated by a *dielectric layer* of shell-lac. The diagram (fig. 142), on p. 197), illustrating the experiment on which Volta established his celebrated *contact-theory,* shows the mode of using this electroscope.

171. A Fulminating Pane (Franklin's Plate) is perhaps the simplest form of electric condenser. It consists of a glass plate, coated on *each* side to about two inches from its edge with *tin-foil,* enclosed in a *wooden* frame resembling a common slate frame. On its under side it is supplied with a small ribbon of tin-foil, which extends from the under coating to a small ring at the edge of the frame; by this means it is connected with a metallic chain which communicates with the earth.

The general construction and mode of charging this apparatus is shown in fig. 96.

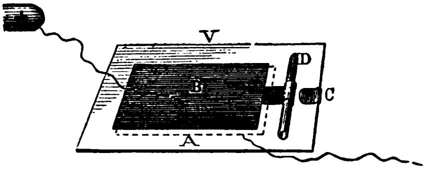


Fig. 96.—SHOWING MODE OF CHARGING FULMINATING PANE.
A, Lower coating of tin-foil connected with the earth.
B, Upper coating of tin-foil.
C, Glass plate separating the two metallic coatings.

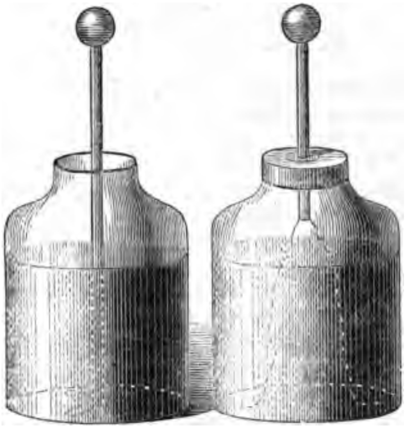
To *charge* the fulminating pane, bring the upper coating of tin-foil into contact, or within *striking* distance, of the prime conductor of the machine at work, the side with the *ribbon* of tin-foil being turned downwards and connected with the ground by a chain, or through the fingers and person of the operator.

172. The Electrified Coin Experiment.—Place a sovereign or a shilling on the *top* of the *fulminating pane.* Charge the condenser, as explained in the last Art. Any volunteer who is not familiar with the experiment is invited to take possession of the coin, on condition that one hand is placed and retained in contact with the *lower* coating while he *raises* the coin with the other. In so doing he receives a powerful electric shock through his fingers, arms, and chest, and but rarely, on his first attempt, succeeds in taking possession of the coin.

173. The Leyden Jar or Phial is the most convenient and portable form of *electric accumulator* or *condenser* in general use for electrical experiments. It owes its name to the city in which it was invented and which it has immortalised.

In its most ordinary form it consists of (*a*) a *glass* jar of suitable thickness; (*b*) of an *inside* and an *outside* coating of *tin-*

foil, reaching to within 2 to 4 inches from the top of the jar; (*c*) a varnished wooden cap fitting into neck of jar and supporting a *brass knob, wire,* and *chain,* terminating below in *contact* with the *tin-foil coating* at the bottom of the *inside* of the jar. These metallic coatings are sometimes termed armatures. For some experiments, as that of the *electric kite* or *fish,* an *open*-mouthed jar (Harris's form) is to be preferred. In this case the knob is supported on a brass wire terminating in a metallic foot resting on the tin-foil at the bottom of the jar.



Harris's Form of Jar. Common Form of Jar.

Fig. 97.—Leyden Jars.

The efficiency of the jar is greatly increased by a coating of *shell-lac* varnish applied to the uncovered portions of the glass. The *shell-lac* greatly retards the *dissipation* of the electricity of the jar, which is otherwise so considerable, especially in badly ventilated gas-lit rooms, or class-rooms in which many people are breathing out moisture, as to interfere seriously even with the performance of ordinary electrical experiments. It effects this by lessening the tendency of the glass surfaces to *attract* and *condense* the moisture.

174. Various Forms of the Leyden Jar may be contrived, as:—

1. A *glass* jar filled ¾ of its height with *water*, and so placed as to be surrounded with the same depth of water on its *exterior*. Such a jar might be charged by a metallic chain passing into the water in the *interior* of the jar; the water on its exterior should be connected with the earth by a conductor.

2. A glass jar filled as before, but held in the *hand*, as large a *surface* of the hand as possible being brought into *contact* with the *outside* of the vessel. This really constitutes the *original* form of the jar, viz.:—that of Cuneus, who (1746) gave himself an electric shock in experimenting with *electrified water*.

3. A glass jar, fitted with cap, knob, and chain, filled ¾ of its interior depth with nails, loosely packed Dutch leaf, surrounded on its exterior, when being charged, by the hand, water, or any conductor.

4. It may also practically be formed by two persons, one standing on a stool with *glass* legs, or on a sheet of *gutta-percha*, and the other on the floor, the two taking hold of each others hands by means of sheets of vulcanized india-rubber interposed between each hand.

175. Essentials of a Leyden Jar.—Many other possible forms of Leyden jars will suggest themselves to the student, the essentials being only those of an ordinary condenser, viz.:—two conductors separated by a not too thick layer of dielectric.

176.*Sir William Thomson's Quadrant Electrometer is the most *sensitive* and useful form of *electrometer* hitherto constructed. It consists essentially of a *charged Leyden jar*, which acts as a reservoir of *free* electricity, by means of which a light flat *aluminium* needle, freely suspended, but in metallic connection with the *interior* coating of the jar, is kept permanently charged with, say, *positive* electricity. Immediately below the flat needle are placed *four brass quadrants*, supported on glass legs. The quadrants are united into two diagonal pairs by means of metallic wires. Each pair of quadrants is supplied with a brass knob or handle (see fig. 98).

To use the instrument, the *body to be tested* is brought into contact with the one knob, while the other is connected with the *earth;* or one knob is connected with the *positive*, and the other with the *negative* pole of a Voltaic couple. The *positively* charged needle will thus be *attracted* by the one set of quadrants and *repelled* by the other. The instrument is protected by a glass shade, the atmosphere in which is kept permanently *dry* by means of a vessel containing *sulphuric acid.*

177. To Charge a Leyden Jar by the Electric Machine.—Case 1 (as ordinarily charged). Bring the knob of the jar into contact, or within *striking* distance, of the knob of the prime conductor of the electrical machine at work, *holding the jar in the hand* by its *exterior* coating, or supporting it by any other suitable means (its exterior coating being in connection with the earth by means of a metallic chain fastened to the gas or water pipe), so as to present the knob of the jar to that of the machine, as described.

Case 2. In which the

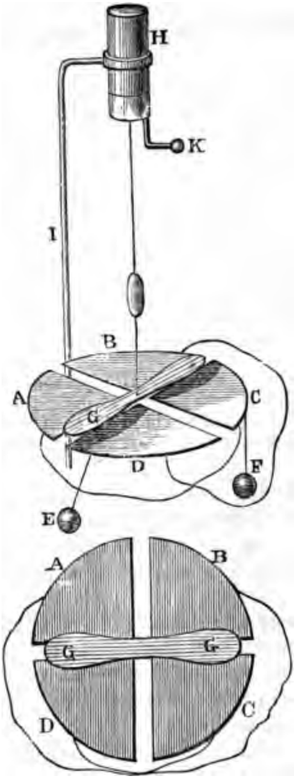


Fig. 98.—Sir William Thomson's Quadrant Electrometer.

A, B, C, D, Four brass Quadrants.

E, F, Brass knobs, one of which is brought into contact with the charged body to be tested, and the other placed in metallic connection with the earth; or one of which is connected with the *positive* and the other with the *negative* pole of the *Voltaic couple* or *battery* to be tested.

H, Small Leyden jar. I, Metal pillar supporting Leyden jar.

K, Brass knob for charging Leyden jar.

interior of the jar is charged with *negative* electricity. Hold the *knob* of the jar in the hand, and bring its *exterior* coating into contact, or within striking distance, of the knob of the prime conductor of the machine at work. Or, what amounts to the same thing, connect the knob of the jar with the earth by means of a metallic chain fastened to the gas pipe; and standing the Leyden jar on an *insulating* stool, bring the *outside* coating of the jar into relation with the prime conductor, during the turning of the machine, as previously described.

The jar will now become charged in a *reversed* manner to that described in *Case* 1, its inside surface now being charged with *negative*, and its outside with *positive* electricity.

178. To Discharge a Leyden Jar by Instantaneous Discharge.—Connect the outside and the inside coatings of the jar with each other by means of a *discharging* rod or a *good conductor*. This is best done as follows:—

(*a*) Bring one of the knobs of the discharging rod (see fig. 99) into contact with the *outer* coating of the jar. (*b*) Now bring the second knob of the discharging rod into contact, or within *striking distance*, of the knob of the *charged* Leyden jar.

Immediately the second knob comes within striking distance of the knob of the jar, the two electricities—the *positive* (in an ordinarily charged jar) from the *inner* surface of the *glass*, and the *negative* from its outer surface—rush together, *unite*, and *neutralise* each other, and thus restore the electric equilibrium of the jar. This combination of the two electricities is termed *electric discharge.*

The *rushing together* of the two electricities just described is attended by the production of a bright *spark* and a more or less loud, sharp, snapping noise, which, on a *miniature* scale, constitutes *thunder* and *lightning*. Where the electric charge is a very powerful one, as in the case of large batteries, it is better to stand the Leyden jar to be discharged on a metallic plate-sheet of tin-foil, and bring the first knob of the discharging rod into contact with it, instead of the outer coating itself, otherwise the jar is apt to be *fractured* at the point of contact.

179. To Discharge a Leyden Jar by Slow Discharge.—(1.) Place the jar, if charged in the ordinary manner, on a *glass plate,* or a glass-legged stool (fig. 45), taking care in so doing to touch its outer surface only.

(2.) Then touch the brass knob connected with its *inner* metallic coating with the finger (a very *small* electric *spark*), and a feeble *snap* and *prick* will be observed by the operator. If the knob be now touched a *second* time in succession, no effect will be produced, the *free* electricity of the inside of the jar having been discharged.

(3.) Now touch the *outer* coating a *second* time (*no effect* having been previously produced when handling the jar in the act of placing it on glass-plate), a feeble *spark,* snap, and *prickle* is observed.

This effect is produced by the discharge of the *free* electricity, just previously *unbound* by the discharge of the free electricity from the inside of the jar by the finger, as described in process 3 of this experiment. If the outside be again immediately touched a second time (the atmosphere being comparatively dry), no effect will be produced.

(4.) Repeat the above processes, *alternately* touching the knob and outer coating in the *order* described. In this way *two or three hundred* or more sparks may be *alternately* drawn from the knob and outside coating of the Leyden jar, its charge becoming continuously less, until at last it gets too feeble to manifest itself by a visible spark. Using the term in the sense in which it is applied by mathematicians theoretically, an *infinite* number of touchings would be required to discharge the jar by process of "*slow discharge.*"

180. The Discharging Rod is an instrument used for *safely* and conveniently discharging the electricity stored up in Leyden jars or other condensers or electricity accumulators (see figs. 99 and 102).

In its most common form it consists of two *curved arms* of thick brass wire, terminating at their *outer* ends in brass knobs, their inner ends terminating in a *compass joint,* firmly attached by a socket to a *glass* handle. The joint enables the terminal knobs to be separated to the distance required by the size of the jar, or of the apparatus to be discharged. The glass handle prevents the electricity passing into the body, a matter of some importance in the case of a powerful battery.

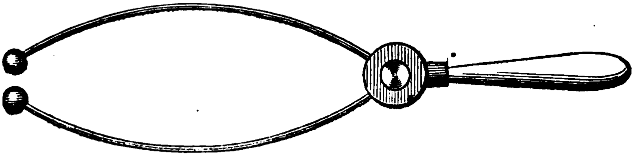


Fig. 99.—DISCHARGING ROD, consisting of two Brass Movable Arms with Glass Handle.

The *French* form of discharging rod possesses *two glass handles*, one attached to each movable arm (see B, fig. 102).

181. Henley's Universal Discharger is the form of discharger most commonly used when it is required to *direct* the charge of a Leyden jar or battery through an object with any degree of precision.

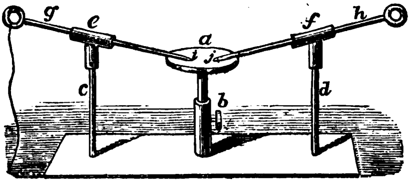


Fig. 100.—HENLEY'S UNIVERSAL DISCHARGER.

a, Wooden or ivory tablet on *pillar*.
b, Screw for adjusting height of tablet.
c, *d*, Insulating (glass) legs.
e, *f*, Brass joints for adjusting points (*ij*) of discharging arms.
g, *h*, Movable discharging arms to be connected with outer and *inner* coatings of battery.

It consists of a wooden stand, on which are supported two insulated discharging arms to be connected with the *outer* and *inner* coatings of the Leyden jar or battery; and an adjustable wooden tablet, with slip of ivory inlaid crosswise for the support of the objects experimented on. Its construction will readily be understood by reference to fig. 100, and its key.

182. A Leyden Battery consists of a series of Leyden jars usually placed in box or tray, the *bottom* of which is lined with *tin-foil*, which thus electrically unites the *exterior* coatings, their *interior* coatings being united by means of brass rods connecting together the knobs of the jars (see figs. 101, 102).

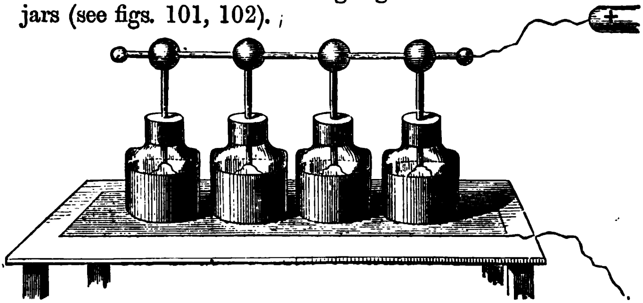


Fig. 101.—Mode of Charging Leyden Battery of Four Jars.

Leyden battery of four jars, the *inner* coatings connected by brass rod joining knobs. the *outer* coatings connected by sheet of tin-foil on which the jars stand.

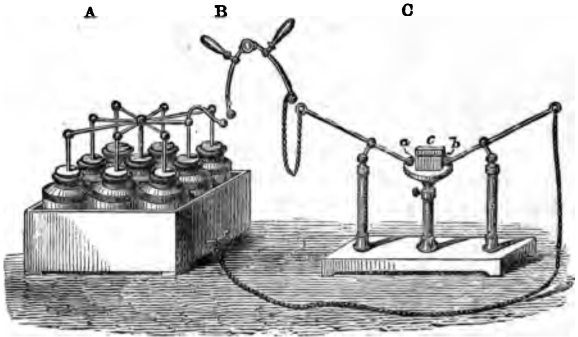


Fig. 102.—Showing Mode of Discharging Leyden Battery through Glass or other Refractory Substance.

A, Leyden battery.
B, French form of discharging rod.
C, Henley's universal discharger.

183.*Charging by Cascade.—A series of *insulated* Leyden jars placed in succession, so that the *tin-foil* coating in the *interior* of the one jar is in metallic connection with the exterior coating of the next, may be charged *simultaneously* by *one* and the *same charge* from the electrical machine (see fig. 103).

In this case the *positive* electricity, accumulated through the action of the machine on the interior of the *first* jar, *repels* by induction through the glass a portion of the *positive* electricity from its *exterior*, which thus liberated, in like manner causes a similar accumulation of *positive* electricity in the *interior* of the next jar; and so the action is repeated through the entire series of jars, positive electricity from the outside of the *last* jar either escaping to the earth, or, if the student prefers it, being neutralised by an equal quantity of *negative* electricity *attracted*, or as it were pumped out of the earth.

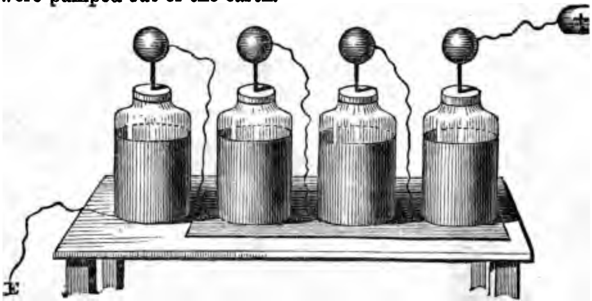


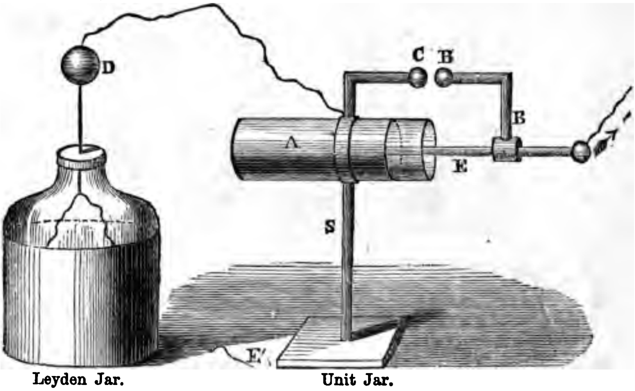
Fig. 103.—ARRANGEMENT FOR CHARGING LEYDEN BATTERY BY CASCADE.

The *inner* coating of each jar is, in this case, connected with the outer coating of the next jar by means of a wire or chain proceeding from the brass knob.

184.*The Harris's Unit Jar is an instrument by which the charge of a battery or large jar is measured by means of a *small* Leyden jar. It usually consists of a small *self-discharging* Leyden jar, 4 to 6 inches long, and 1 to 1½ inches diameter, supported *horizontally* on a *glass* leg with iron foot (see fig. 104).

To the brass rod (which is roughly graduated) supporting the knob connected with the *inner* coating of the jar, is attached a *movable* arm, sliding along the horizontal rod by means of a spring or tube, so that it may be set at at any fixed distance from a second brass knob connected with the *exterior* coating. If the sliding knob be brought *near* the latter when the interior coating is in connection with the electrical machine at work, the discharges between these knobs succeed each other *rapidly*, but are of *low tension;* but if the knobs be placed much farther apart, the *discharges* are much less rapid, but are of far *higher tension.*

When the *knob* communicating with the *interior* of the *unit jar* is connected with the electrical machine at work, its *outer* coating being in communication with the knob of the *Leyden battery* to be charged, the latter will become charged with as many times the electricity contained by the former, as is equal to the number of *electric sparks* passed between the knobs of the *unit jar* during the process of charging the *battery.* The battery in the case is charged by the positive electricity *repelled* from the outside of the unit jar.



Leyden Jar. Unit Jar.

Fig. 104.—SHOWING MODE OF MEASURING CHARGE OF LEYDEN JAR BY MEANS OF HARRIS'S UNIT JAR (A).

A, *Outer* coating of jar.
B B, Brass knob and movable arm sliding on E.
C, Brass knob and arm connected with outer coating.
D, Brass knob of Leyden jar in connection with outer coating of unit jar.
E, Brass knob of *interior* coating at present in connection with electrifying machine.
E', Wire connecting *outer* coating of Leyden jar to be charged with the *earth.*

To Use the Unit Jar, connect or bring into contact with the prime conductor the knob communicating with its *inner* coating, connecting or bringing into contact its outer coating with the knob of the Leyden jar to be charged (see fig. 104). On working the electrical machine, a series of *discharges* will take place between the knobs of the *unit jar.* Each time such discharge takes place, a quantity of positive electricity will have entered the *interior* of the jar to be charged, *repelled* from the *exterior* of the *unit jar,* equal to that collected from the machine on its interior surface. Consequently, the Leyden battery, or larger jar, will be charged with as many times as much electricity of the same *tension* as that contained in the *unit jar,* as there were of discharges of the latter in the charging of the former. Thus, if ten discharges took place between the knobs of the *unit jar* during the charging of the *battery,* the latter would contain ten times as much, if forty discharges, forty times as much electricity as the former. The construction and use of the unit jar are clearly shown in fig. 104.

185. The Electric Charge Resides in the Outside of the Glass, and not in the Metallic Coatings.—Charge a Leyden jar with *movable* tin coatings (see A, fig. 105) in the ordinary way, and after placing the charged jar on a *glass* plate, then:—

1. Remove the *inner* tin coating, I, by means of the glass tube *t,* and place it in the *interior* of the *uncharged* glass jar, B.
2. Remove the *outer* coating, O, and place it on the exterior of the *uncharged* jar, B.
3. Lastly, replace the coatings removed from the *charged* glass jar, G, by fresh tin coatings, C and D.

If the two Leyden jars be now *discharged,* that containing the glass jar originally charged will be found to contain a *powerful,* while that containing the tin coatings, originally charged, will be found to contain only a very *feeble* electric charge; thus proving the charge to be confined almost exclusively to the *surfaces* of the *glass.*

186. Residual Charge.—After a Leyden jar has been once *discharged,* a second, and even third, or fourth discharge, may be obtained after short intervals of time;

thus showing that a portion of its charge must have *penetrated into*, or rather *below*, the surface of the glass. The feeble charge thus retained is termed the *residual* charge, or the *electric* residue. The residual charge is sometimes termed the secondary, tertiary, etc., charge.

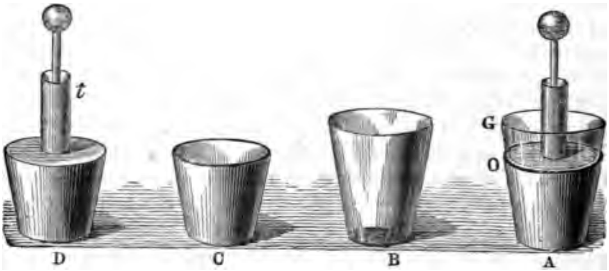


Fig. 105.—DISSECTED LEYDEN JAR WITH MOVABLE TIN COATINGS.

A, Leyden jar with movable tin coatings (O, outer; I, inner coating; and G, glass jar).
B, Glass jar with metallic coatings removed.
C, Outer coating.
D, Inner coating, with glass tube (*t*) for removing and replacing it in interior of tube.

187. Experiments I.-XIII.—Physiological, Physical, Luminous, Chemical, etc., with Electrifying Machine.

EXPERIMENT I. — **The Human Body on Glass-legged Stool.**— If a person standing on a stool with glass legs touches the prime conductor, or holds a brass chain connected with the prime conductor, on turning the machine he becomes (forming practically part of the prime conductor) charged with positive electricity. Accordingly, as the *hair* of his head *diverges* from self-repulsion ("stands on end"), he experiences a peculiar tingling sensation about the face; if he touches the disc of a gold-leaf electroscope the leaves will *diverge;* if he bring his knuckle near the *pith ball* of an electric pendulum it will be *attracted;* if he bring his finger near another person, or if any other person bring his hand near him, an electric spark, attended with a snapping noise, will pass between them, each mutually experiencing a sharp, pricking sensation. Also, if he place his finger immediately over a gas jet from which gas is issuing, or if the gas jet be brought near any part of his person, or his clothes, the gas will be fired by his person.

EXPERIMENT II.—**Electric Shock.**—If a Leyden jar or battery be discharged through the human body, or a chain of persons holding each others naked hands closely, a peculiar and not very agreeable sensation is produced, termed the *electric shock.* It is due to the discharge or recomposition of the *neutral fluid* by the recombination of the *positive* and *negative* fluids within the body; it is chiefly felt about the *joints* of the arms.

EXPERIMENT III.—**Electrical Hail.**—Electrify the *inside* of a warm glass tumbler, and invert over a piece of *tin-foil* (in connection with the earth), on which are placed a number of pith balls. They will immediately begin to dance about in the most eccentric and amusing manner possible. The experiment is best performed by placing the pith balls between two metallic plates, one of which is in connection with the earth, as shown in fig. 106. If, instead of the balls, two small pith figures be used, the effect will be still more amusing.

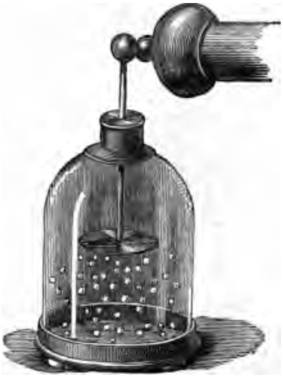


Fig. 106.—ELECTRICAL HAIL.
Showing pith balls dancing between two metallic plates, one in connection with electrical machine at work, the other in connection with the earth.

EXPERIMENT IV.—**Electrical Whirl, Orrery, and Chimes.**—Balance a metallic wheel, the ends of the *radii* of which, terminating in *points,* are all *bent* sidewise in the same direction, on a point inserted in the *prime conductor,* as shown in fig. 107. On working the machine, a powerful wind, the electrical aura, will be produced, which, reacting against the points, will drive the wheel round with great velocity. If the principal wheel, instead of being made to revolve itself, be made to support other wheels rotating with little balls, the motion of the earth and planets may be readily imitated, the arrangement is then termed the *electrical orrery.* If the *whirl*

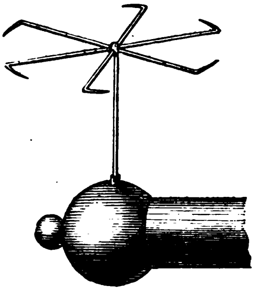


Fig. 107.—ELECTRICAL WHIRL.

is made to carry a pendulous wire or weight, which, as it revolves with the whirl, is made to *strike* a series of bells placed below, the experiment is described as the "*electric chimes.*"

EXPERIMENT V.—**Electrified Water.**—Place a small quantity of water in a brass vessel connected with the prime conductor, and containing several capillary apertures *too small* for the water to escape from (see fig. 108). On working the machine, the water will immediately be *driven* out of the vessel by electrical *repulsion.*

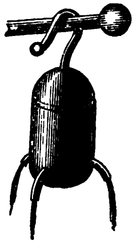


Fig. 108.—ELECTRIFIED WATER.

The vessel is filled with water, the holes being so small that the water either hangs in drops or falls, one drop at a time, until electrified, when it runs out in a continuous stream.

EXPERIMENT VI. — **To Explode Gunpowder by the Leyden Battery.**— Pass the electric charge on its way from the jar to the gunpowder through a piece of *wet string* of suitable *length,* or a basin of water, in order to *retard* its velocity, otherwise the act of *discharge* will have been completed *too rapidly* to permit of the *firing* of the gunpowder.

EXPERIMENT VII. — **Electrified Egg, Lemon, Loaf Sugar, and other Substances.**—Discharge the Leyden battery by means of the universal discharger, or any other convenient arrangement, through a *lemon,* through a piece of *loaf sugar,* or through two or more *eggs* placed in *contact endwise;* most beautiful luminous effects are produced at the moment of discharge, also through powdered chalk, barium sulphide, calcined oyster shells.

EXPERIMENT VIII.—**To Fire a Piece of Tow.**—Dust the tow over with *powdered resin,* attach loosely (so as readily to shake off) to one of the knobs of the discharging rod; discharge the Leyden jar through the powdered tow, taking care to bring the *tow* to the *knob* of the jar to be *discharged.*

EXPERIMENT IX.—**To Magnetize a Steel Needle.**—Place the needle to be *magnetized* near and at right angles to a conducting wire through which a large Leyden jar or battery is *discharged;* or still better, place it in a glass tube round which a copper wire is coiled (see figs. 14, 15), and *discharge* the Leyden battery through the coil.

EXPERIMENT X.—**Melted Sealing-wax Experiment.**—Melt some sealing-wax on the point of a wire, and insert in hole in prime conductor; work the machine vigorously, and the melted sealing-wax will immediately, if skillfully managed, spurt out into threads and branches, assuming a more or less distinctly marked arborescent form.

EXPERIMENT XI.—**To Perforate a piece of Card.**—Pass the electric spark from the discharge of a Leyden *battery* through the card. The card will be found perforated, a slight *burr* outwards appearing on each side of the card as though a fluid or other substance had passed *out* from each side of the card. This was formerly regarded as evidence of the two-fluid nature of electricity. In general a battery of *two* or more jars is required to perform this experiment. If, instead of a single card, 10 or 12 sheets of paper be interposed and perforated by the discharge, about *half* the number of the sheets will appear as though they were pricked or pierced from the *one* side, and *half* from the *other* direction.

EXPERIMENT XII.—**To Fire Alcohol or Sulphuric Ether.**—Place the *alcohol* in a shallow, rather wide glass vessel. Hold a brass chain 18 to 24 inches long in contact with the *outside* of a charged Leyden jar, the other end dipping into the bottom of the alcohol to be fired, then bring down the knob of the jar till the spark passes from the end of the chain *through* the spirits to the knob. The alcohol will be fired. It is better first to *warm* the alcohol; if the experiment be made with *ether*, this is however unnecessary. It is sometimes difficult to perform this experiment in the absence of the special apparatus constructed for the purpose.

EXPERIMENT XIII.—**To Make Electrical Portraits.**—Take a piece of thin card, and cut out the desired portrait or design in the card (*d*, fig. 109) by cutting away thin strips after the manner of the so-called "shadow pictures." Gum a small sheet of tinfoil to each end of the card (*e* and *f*) containing the design. Then lay it across one of the tables of the press as shown by *c*, and

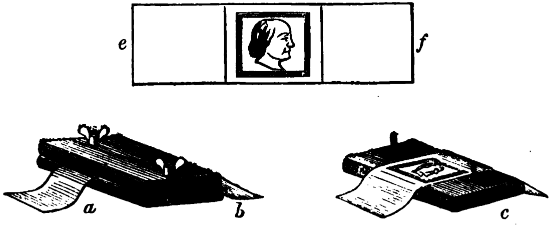


Fig. 109.—ARRANGEMENT FOR TAKING ELECTRICAL PORTRAIT.

a, *b*, Press ready for discharge.
c, Shows arrangement in the interior of the press.
d, Portrait, the lines of which are formed by cutting out narrow strips from the substance of the card.
e, *f*, Sheets of tin-foil gummed on to ends of card containing the design.

cover it over with a sheet of gold leaf, on which place a white silk ribbon or a card, then screw it down in the *press* as shown by *a b*. Place the *press* on the table of the *universal discharger*, and discharge the battery through it. On unscrewing the press, the volatilized gold driven through the lines cut in the pattern card will be found impressed on the silk or card in the form of a fac simile of the original design.

188. The Electric Kite or Fish.—Cut a piece of *gold leaf* about 2 inches long into the form of a boy's *kite*, or of a *fish*. Take it up on the end of a glass rod, and disengage it from the rod in the air in the immediate vicinity of, but yet so as not to touch, the brass knob of a *charged* Leyden jar. The Harris's form of Leyden jar (fig. 97) with open mouth answers best for this experiment. The *gold-leaf kite* will now *float* alone in the air, sustained by the air currents proceeding in opposite directions from its head and tail, which are produced by the passage of *negative* electricity *to* and *from* the opposite points of those extremities. If a metal rod be held *near*, and moved about the end more remote from the knob of the jar, the miniature kite will follow it up and down, and round the knob.

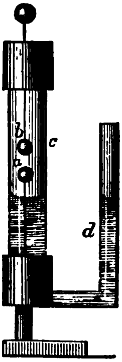


Fig. 110.—Kinnersley's (Electric) Thermometer.

a, Fixed brass knob.
b, Sliding brass knob.
c, Larger tube charged with alcohol.
d, Smaller tube opening into *c*.

189. Kinnersley's Electric Thermometer is an instrument used for illustrating the *repulsive* power of electricity as exerted on the air. How much of the effect produed is due to simple *electric repulsion*, and how much to the *expansion* caused by the *heat* generated by the passage of the electricity through the resisting air, is, however, at present mere matter of opinion. Kinnersley's thermometer consists, as shown in fig. 110, of two tubes *c* and *d* (of which the one *c* is much larger than the other *d*), united at their bases by a cross tube. To the top of the larger tube is fitted a brass cap, with spring tube traversed by a sliding wire, terminated at each end by a brass ball. The lower end of the tube is fitted into a similar brass cap supporting a wire terminating in fixed brass knob. The vessel is filled to just below the lower knob with water, or still better, because of its greater mobility, alcohol.

On passing an electric spark between the brass knobs, the liquid is projected (up the tube *d*) with considerable violence, rising in the case of a powerful spark to a distance of many feet.

190. The Spangled Tube or Pane.—If a glass tube or pane be covered with small circular pieces of tin-foil (spangles) about $\frac{1}{16}$ or $\frac{1}{8}$ of an inch in diameter, gummed on the surface of the glass, at a distance of $\frac{1}{8}$ of an inch from each other, so as to form a design or picture, the spangles being continued from the commencement and termination of the design to the opposite edges of the pane, or the ends of the tube, most beautiful *luminous* effects will be produced on passing electric sparks through the same in the dark. The whole of the design will be seen apparently pictured out in fire.

Spangled Leyden jars, which exhibit beautiful *luminous* effects on being *charged* and *discharged*, are constructed in a somewhat similar manner.

191. Eudiometers—Chemical Effects of Electricity.—When an electric spark is passed through a mixture of *oxygen* and *hydrogen* gases in the proportion of *one* of the former to *two* of the latter, or where these gases are mixed in anything like these proportions, it immediately causes them to combine *chemically* with a loud explosive sound, so as to form *water*. If the vessel be not sufficiently strong, it will be shattered into pieces.

A *eudiometer* usually consists of a graduated glass tube (see fig. 111), one end of which is closed, the other open. Near the *closed* end two *platinum wires* with blunt ends are soldered into the glass tube, between the inner extremities of which a space should be left.

To use the eudiometer, fill the tube two-thirds full of the mixed gases, the remainder being filled with water, and the lower end tightly closed by the end of the thumb; then pass an electric spark from a common electrical machine, or from the *electrophorus*, placing one of the platinum wires in connection with the machine, or the *collecting plate* of the electrophorus, and the other wire in connection with the earth by means of a metallic chain, or more conveniently by touching it with the knuckle. An *explosion* followed by condensation immediately takes place, and on removing the thumb from the tube (under water) more water rushes into the tube.

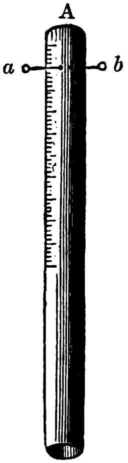


Fig. 111.—EUDIOMETER TUBE FOR COMBINING OXYGEN AND HYDROGEN BY MEANS OF ELECTRIC SPARK.

A, Graduated glass tube. *a*, *b*, Platinum wires terminating exteriorly in rings or knobs.

192. A Volta's Pistol consists of a brass tube constructed on the same principles as the *eudiometer*, mounted on a wooden handle shaped like a pistol stock. In this case it is necessary, in order to ensure the passage of the electric spark through the mixed gases in its interior, and not through the substance of the metallic tube itself, to insert one of the wires through which the spark is to be made to pass, not into the metallic wall of the tube itself, but into a *peg* or *plug* of *ivory* or *vulcanite* let into its side. When an electric spark is passed through such a tube, its mouth being stopped by a cork, a loud explosion, accompanied by the sudden expulsion of the cork, takes place.

193. A Volta's, or Electric Mortar, or Bomb, is an instrument constructed (best of *ivory* or *vulcanite*) on similar principles, but on a much *larger* scale. In this case *common air* only is used. When a powerful electric spark is passed through the *air* contained in the interior of such tube, usually constructed in the form of a mortar or bomb, its mouth being stopped by an accurately fitting *light* wooden ball, the ball is forced out, and projected by the expansion thus developed. Thunder is produced by similar atmospheric expansion, due to the passage of lightning.

194. Action of Flame.—*Flame* tends to *dissipate* electricity. (1) It acts as a *point* because of its form. (2) It acts as a partial *vacuum*, because of the highly *rarefied* air it encloses.

EXPERIMENTAL PROOF.—Place a short piece of candle, also a Henley's Quadrant Electrometer on the prime conductor of a machine at work, light the candle, the pith ball of the electrometer immediately falls. (2) Bring the flame of a candle near the prime conductor of an electrical machine at work, the pith ball of the electrometer immediately falls. (3) In discharging a Leyden jar, bring a *broad* lamp flame, or the candle *flame spread out* by flattening the wick, between the knobs of the discharging rod and of the Leyden jar, the *striking distance* will be greatly *increased*.

195. Action of Points on Flame.—Bring the *flame* of a candle near a metal *point* inserted in the prime conductor of an electrical machine at work (see B, fig. 112), the flame will be *blown* about violently, and if held in the right position, extinguished by the *wind* produced by the escape of the *positive* electricity.

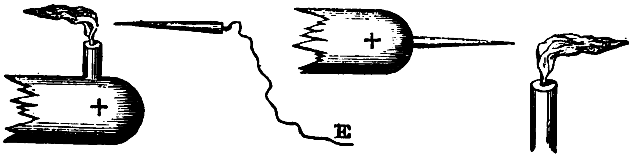


Fig. 112.—SHOWING ACTION OF POINTS ON FLAME.

EXPERIMENT.—Place a short piece of *lighted* taper on the prime conductor, and bring a *point*, either held in the hand or connected by a wire with the earth, near the *flame* of the taper. The *flame* will be blown about or extinguished as before, but this time by a wind blowing *from* the metal point produced by the escape of a stream of *negative* electricity passing *from* the earth *to* the prime conductor (see A, fig. 112).

196. Nature of the Electric Spark—Disruptive Discharge.—When electricity, because of its *high tension*, escapes through air, gases, or other transparent *insulators*, or through a vacuum, it gives rise to certain luminous phenomena, the chief of which are the electric *spark*, *brush*, and *glow*. The electric *spark* is produced by *discontinuous electric* discharge, its *colour* is due to the minute particles of ponderable matter it *disrupts*, and carries over with it from the surface of the conductor from which it escapes, and is therefore chiefly due to the nature of the material of which the conductor is composed. When the distance between the conductors is *short*, the spark (really a *line* of light) is *straight* as

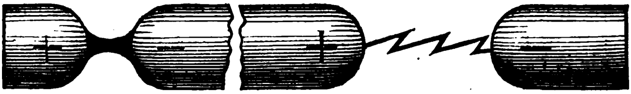


Fig. 113.—Straight and Zig-zag Electric Sparks.

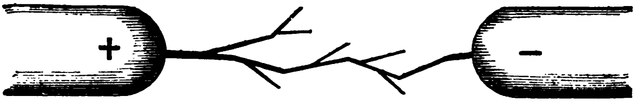
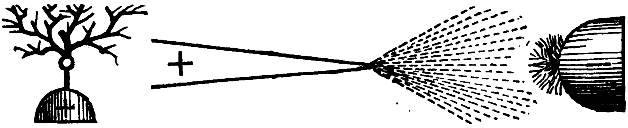


Fig 114.—Forked or Branched Electric Spark.



A Fig. 115.—Showing Electric Glow, Brush. C

A, Electric *glow* from *positive* conductor; C, from *negative* conductor. B, Electric brush.

shown; when the conductors are removed farther apart, at a certain distance the spark becomes *zig-zagged;* and when the conductors are removed a still greater distance from each other, it becomes *forked* or *branched.*

The Brush is the *continuous,* radiating, *brush-like,* luminous discharge, accompanied by a slight hissing noise, but visible only in the *dark,* which issues from a *point* attached to a conductor charged with electricity of high *tension,* especially when it is adjacent to another conductor

The Glow is the star-like point of light which issues from a conductor charged to a state of high tension, especially when no other conductor is near. The *glow* from a conductor charged with *positive* electricity is greater than that from a conductor charged with *negative* electricity.

197. Lightning is simply the *electric spark* on nature's own grand scale; it presents, under special conditions, all the peculiarities of form described in the last article.

Heat or *summer* lightning, or, as it is frequently termed, *sheet* lightning, most probably consists of electric discharges taking place between clouds at such remote distances from each other as to be *below* the horizon, and too far from the observer to permit of the accompanying thunder being heard. The *lightning* sometimes presents itself in the shape of a *ball of fire,* it is then described as "*globe lightning;*" the precise cause of this phenomenon has not yet been satisfactorily explained by physicists.

198. Duration of Electric Spark or Lightning Flash.—The instantaneity of a flash of lightning, or of the electric spark, is shown by the fact that a cannon ball during any portion of its rapid flight, when projected through darkness from the mouth of a cannon, if seen during the momentary illumination of the lightning, appears to stand perfectly still and motionless. This is due to the fact that the duration of the lightning is less than one-eighth of a second. If the illumination due to the flash lasted so much as one-eighth of a second, the moving cannon ball would present the appearance of a black line, just on the same principle that a lighted stick, moved rapidly backwards or forwards, presents the appearance of a line of fire. From a similar cause a wheel, or a Newton's disc, rotating so rapidly on its axis that neither the spokes of the wheel nor the colours of the disc can be distinguished, when seen under the momentary illumination of the electric spark, appears to stand out perfectly distinct and motionless, the spokes or the colours being most distinctly visible.

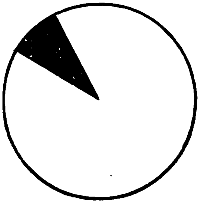


Fig. 116.—ROTATING DISC FOR PROVING INSTANTANEITY OF ELECTRIC SPARK.

EXPERIMENTAL PROOF.—Cut out a disc of white cardboard 10 or 12 inches in diameter, paint a black *sector* in the same as shown in fig. 116, pass a pin through the centre of the disc, and *rotate* rapidly in the dark. Illuminate the disc while thus rotating by the spark obtained from a powerful electric machine, or by the discharge of a Leyden jar. The white and black portions of the disc will appear, during the moment they are visible, to stand out clearly and distinctly, and apparently *quite still* and motionless. If the disc thus rotating be viewed by ordinary daylight, it will appear of one uniform greyish tint.

199. The Velocity of Frictional Electricity has been determined by Professor Wheatstone, by means of several miles of copper wire broken at three points (so as to yield three sparks by the same discharge), and a *rotating mirror*, to be about 288,000 miles per second. The velocity of electricity under these circumstances thus exceeds that of light. For the nature of this proof, see *Magnetism and Electricity* in the Advanced Series by Professor Guthrie.

200. Thunder is the loud report which usually accompanies the lightning's flash. It arises from the *sonorous* aërial vibrations produced by the displacement of the aërial particles suddenly repelled by the passage of the electric fluid, which thus on its course *rarefies* and *expands*, by its *heat* and its *repulsive* powers, large masses of air; the *elasticity* of the air immediately after causing its particles to *rebound*, sets up a series of *condensations* and *rarefactions* throughout its mass which thus constitute the acoustic cause of thunder.

The rolling or *reverberation* of thunder is probably due in part to *reflection* among the clouds, and in part to the *ziz-zag* course of the lightning itself, the same flash being in many cases within incredibly short periods of time, now very near, now very distant.

201. A Lightning Conductor is a long, *continuous* metallic rod, terminating above in one or more gilt points, and below, deep down in the moist earth, in a well, or the bed of a river, or in connection with the water pipes.

It acts chiefly by *induction*, discharging by means of its points from the earth into the cloud, electricity of the *opposite* kind to that of the *storm-cloud* itself, *simultaneously* discharging that of the cloud into the earth. It thus tends to prevent the accumulation of electricity in the clouds, acting in this respect as the *points* of the *prime conductor* act on the *glass-plate* of the electrifying machine at work (see Arts. 143 and 158). It also tends to *attract* and conduct the lightning harmlessly to the ground after it has once formed.

The *conductor* should be carried 8 or 10 feet above the highest point of the building to be protected; if not continuous, that is, if any part of it be *broken* or *disconnected*, it becomes a source of great *danger*.

202. Places of least danger during a Thunderstorm. —*In an open field*—Away from a river, lake, or marshy ground; in a *dry* ditch or hollow; also at a distance from tall trees equal to one-half to two-thirds of their height. *In the house*—In the middle of the room, especially if carpeted; in bed, more particularly if between the blankets, and on a wooden bedstead away from the walls, bell-wires, the windows, and the chimney.

203. Living Frog and Electrical Machine at Work. —If a living frog be placed near, but not in connection with, a common electrical machine at work, every time a spark passes from the prime conductor its body will become violently *convulsed*. These convulsions result from *return shock*, being produced by the *separation* by *induction* and instantaneous *recomposition* of the two electricities in the body of the frog, as described in Art. 204.

204. The Return Shock, Shock by Influence, or Back Stroke, is the electric shock, sometimes fatal, which strikes down persons at a distance, occasionally of several miles, from the point of the lightning's discharge. It is produced as follows:—Let us suppose a bank of thunder-cloud, many miles in length, *powerfully* charged with *positive* electricity, in such a case the ground and objects immediately *below* would, under the *inductive* influence of the cloud (which would attract their *negative* and repel their positive electricity), become powerfully charged with *negative* electricity, the charge equally affecting *living beings* and inanimate objects. Let us now suppose that the tension of the *positively* charged thunder-cloud suddenly became so great as to cause it to discharge from one of its extremities to the earth. Electric equilibrium would thus immediately be restored, not merely at the point of the lightning's discharge, but even at points under the other extremity of the cloud, and 10 or 12 miles distant from the lightning. The sudden *recombination* of the *two electricities* in the body of a person *negatively* electrified by induction, consequent on the *cessation* of the inductive agency of the lightning, or rather of the electric force which produces it, would, in many cases, cause death. Sometimes, on the passage of the lightning from one end of the thunder-cloud to the earth, equilibrium is immediately restored by a flash of lightning from some point of the earth under the other end of the cloud: to this phenomenon the term *back stroke* is more particularly applied.

A precisely similar phenomenon to that of the *return shock* is produced on a smaller scale when a person stands near a very *powerful* electric machine at work. Every time such a machine is *discharged*, or a *spark* taken from it by some other person, an electric shock is felt, even when no connection exists between the person affected and the machine. (See Art. 206.)

205. The following diagram will probably assist the student in more fully comprehending the instructive and interesting phenomenon of *return shock*. Let the *positively* charged glass rod A, fig. 117, represent a cloud charged with *positive* electricity, and let the portion of the ball E, acted upon inductively by the excited glass rod, represent so much of the earth's surface as may be acted upon by the *positively* charged cloud. Its outer surface, together with the objects resting upon it, would thus become charged (by induction) with *negative* electricity, the *positive* electricity being driven *deeper* down into the substance of the ball. It is evident that if (1) the excited glass rod be now *removed;* or (2) if its electricity be *neutralised* by discharge from another body, say B, fig. 118, charged with the *opposite* electricity, that the two *separated* electricities in the ball E would immediately recombine, and that this *sudden recombination* of the two electricities would produce *electric shock* (return stroke) in any minute living animal resting on the surface of the ball so affected.

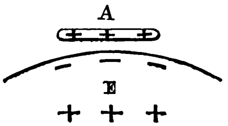


Fig. 117.

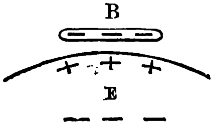


Fig. 118.

EXPERIMENTAL ILLUSTRATION OF THE PHENOMENON OF RETURN SHOCK.

A, Excited glass rod representing cloud charged with *positive* electricity.
B, Excited rod of sealing-wax representing cloud charged with *negative* electricity.
E, Portion of large ball illustrating *distribution* of electricity on earth immediately prior to *return shock.*

All insulated *electrified* bodies act similarly upon the tables, walls, or furniture of the rooms in which they are contained.

The *negatively* charged rod of *sealing-wax* B, fig. 118, similarly illustrates the action of a *negatively* charged cloud in producing *return shock.*

206. Firing a Gas Jet by Return Shock (that is, by *induction*).—Let a person wholly *un*connected with, and standing 7 to 10 feet distant from a *powerful* electric machine at work, hold a *point* or a *knife blade* immediately over (but so as not to touch) a common gas burner, from which the gas is escaping. Every time a *long* spark is drawn from the machine, a small spark passes between the point of the knife and the gas burner, which kindles the gas. In this case the body becomes charged with *negative* electricity under the *inductive* influence of the *positively* charged prime conductor. On the sparks passing, the prime conductor loses its *positive* charge, and consequently its *inductive* power, the body therefore instantaneously loses its *negative* charge, a portion of its electricity escaping on its way to the earth, with the production of the electric spark from the point through the mixture of air and coal-gas to the burner, and thus firing the gas. The student will observe this experiment is quite different to that of firing a gas jet by the *direct* spark. He should also be careful not to confound, as is frequently done by young students, "Return shock" with "Return charge."

A *Volta's pistol* held near an ordinary machine, its knob or wire being connected with the ground, may also be fired in the same manner, that is, by the *inductive spark*, on drawing a direct spark from the machine to some other object.

The only machine of moderate dimensions by which the experiment just described can be performed with any certainty is the Winter's plate machine, with large *ring*.

CHAPTER XI.

VOLTAIC, DYNAMICAL, OR CURRENT ELECTRICITY.

207. History of Voltaic or Galvanic Electricity.—This branch of modern physics, probably one of the most interesting of the group, is popularly said to have had its origin in the illness of a distinguished Italian lady, the daughter of one Italian professor and the wife of another, Professor Galvani of Bologna. The late distinguished philosopher, Arago, says—

> "It may be proved that the immortal discovery of the Voltaic pile arose in the most immediate and direct manner from a slight cold with which a Bolognese lady was attacked in 1790, for which her physician prescribed the use of *frog broth.*"

Galvani himself says concerning his discovery, in a paper published in 1791,

> That he was "dissecting a frog on a table on which stood an electrical machine, when the limbs suddenly became *convulsed* by one of his pupils touching the *crural nerve* with a dissecting knife at the instant that a spark was taken from the prime conductor of the machine."
>
> Following these experiments out, he attached the legs of frogs and warm-blooded animals to a pointed conductor fixed at the top of his house, and found that they were violently *convulsed* at every flash of *lightning.*
>
> "In prosecuting these researches he happened to suspend some frogs on copper hooks fixed in the spine, and with this arrangement he observed the contractions in all states of the weather when he connected the copper hooks with the iron rails."

All these effects, except the latter, were produced by *induction.* Inferring they might be produced independently of the electric condition of the atmosphere, he found he could readily produce them in his own room whenever he connected the *crural nerve* with the *external muscle* by means of a bar of two *dissimilar* metals. Galvani himself, Professor of Anatomy, though accurate in the statement of his facts, explained them erroneously on his theory of *Animal Electricity.*

Volta, Professor of Physics at Pavia, studied and repeated Galvani's experiments; and, after inventing and introducing the *condensing electroscope* as an instrument of research into these investigations, further, in the year 1800, invented the celebrated Voltaic pile. About the same period he also developed his *contact theory,* according to which he explained all these effects as due to electricity generated by the *contact* of dissimilar metals.

Immediately following this period came the investigations of Sir Humphrey Davy, and our own Faraday, the statement of the importance and extent of whose brilliant researches alone would far exceed the entire limits of this treatise, while at the present date the labours of Sir W. Thomson, Tait, Clerk Maxwell, Jenkin, Foster, Tyndall, Guthrie, and others, are extending, consolidating, and popularising the science with unexampled success.

208. The Simplest Form of Apparatus for Generating and Transmitting a Voltaic Current consists, as shown in fig. 119, of (1) A glass or earthenware jar containing dilute *sulphuric acid*, or a solution of *common salt*.

(2.) A *zinc* and a *copper* plate immersed in the liquid.

(3.) Two copper wires, one fixed (best soldered) to the *upper* part of each plate.

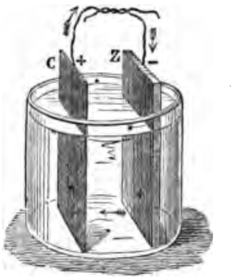


Fig. 119.—A Voltaic Element or Couple in Closed Circuit.

One of the simplest forms of apparatus for generating and transmitting a Voltaic current, consisting of a copper and zinc plate and connecting wire. The two former immersed in dilute acid.

When the two *free* ends of the copper wires are brought into *contact* with each other, as shown in the figure, a *current* of *positive* electricity is generated, which passes *from* the zinc *through* the liquid *to* the copper, and, traversing the copper plate, from it *through* the wires *towards* the zinc. At the same time a *current* of *negative* electricity is supposed to *start* from the immersed part of the copper plate, travelling in the *opposite* direction *through* the liquid *to* the zinc plate, and out of the cell from the zinc by the wire connected with it, towards the copper. These *theoretical* movements are distinctly indicated in fig. 119.

209. Fundamental Experiments in Voltaic Electricity.—Apparatus required:—(*a*) *Two* strips of sheet *zinc* 3 to 4 inches long, and ½ inch to 1 inch broad, one of them *amalgamated.* (*b*) *A* strip of clean sheet *copper* same size. (*c*) *A* small glass vessel or a short test tube containing a little *sulphuric* or *hydrochloric acid,* diluted with 6 or 8 times its bulk of water (see figs. 120-122).

EXPERIMENT I.—Immerse the strip of *un*amalgamated zinc in the dilute acid, it will immediately begin to *effervesce* from the escape of *hydrogen gas* which attends the *solution* of the *zinc,* the immersed surface of the zinc becoming more or less covered with bubbles of the gas.

EXPERIMENT II.—Now dip the strip of copper into the liquid (as shown in fig. 120), taking care the metals do *not* touch. No *apparent* change takes place on the surface of the *zinc.* But the plates are said to be *polarized,* the *immersed* part of the *copper* plate becoming −, and the non-immersed portion +, while the *immersed* part of the *zinc* plate becomes + and the *dry* portion −. Professor Jenkin, however, states that this is an error, no such state being brought about until the *zinc* is brought into *contact* with *its connecting* wire.

EXPERIMENT III.—Bring the immersed metals into *contact* below the surface of the liquid (see fig. 121). The *hydrogen gas* immediately becomes to all appearance transferred to the surface of the copper, from the back, front, and edges of which it escapes very freely. If the *zinc* is tolerably *pure,* little or no *hydrogen* now escapes from its surface.

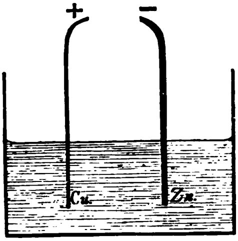


Fig. 120.—ILLUSTRATING THE ORDINARY THEORY OF ELECTRIC CONDITION OF PLATES OF COPPER AND ZINC BEFORE METALLIC CONTACT.

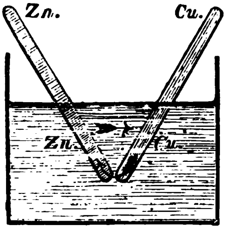


Fig. 121.—SHOWING GALVANIC ACTION OF ZINC AND COPPER PLATES WHEN CONTACT IS MADE UNDER SURFACE OF DILUTE ACID.

EXPERIMENT IV.—Repeat the last experiment with the strips of *copper* and *zinc,* making the *contact* between the metals *out* of the liquid as shown in fig. 122. The same results, including the singular *apparent transfer* of the hydrogen, takes place. Similar results are also produced when, in place of the contact just described, the metals are *connected* by metallic wires as shown in fig. 119.

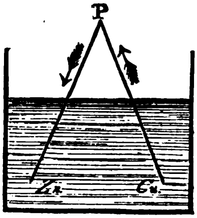


Fig. 122.—SHOWING GALVANIC ACTION OF COPPER AND ZINC PLATES WHEN CONTACT IS MADE ABOVE THE SURFACE OF DILUTE ACID.

EXPERIMENT V.—Repeat Experiments I. and II. with the strip of *amalgamated* zinc. *No hydrogen gas* will be evolved in either case. Repeat Experiments III. and IV. with the same strip of *amalgamated* zinc. The *hydrogen* will be evolved *freely* in each case, but from the surfaces of the *copper only*. No hydrogen whatever will be evolved from the surface of the zinc if it be properly *amalgamated.*

In each of the experiments just described a current of *positive* electricity (indicated by the arrows in the figures) is supposed to be either *originated* or *sustained* by the chemical action of the liquid on the zinc, which current, commencing at the surface of the zinc plate, passes from it through the liquid to the copper, and through the copper back again to the zinc.

The *molecules* (particles) of the liquid, through which the current passes, are supposed to undergo *polarization* (see Art. 129), by which their *invisible transfer* is effected.

Thus the + *zinc* plate is supposed to attract and *turn* towards itself the *negative oxygen* of the molecule of *water* next to it. The − copper plate similarly and *simultaneously* attracts and *turns* towards itself the + *hydrogen* molecule of the *water*. These changes of aggregation are shown by the following formulæ:—

$$\left.\begin{array}{c}\textit{Before}\text{ the}\\ \text{current.}\end{array}\right\}\begin{array}{ccccccc}\mathrm{Cu} & \overbrace{\mathrm{H_2O}} & \overbrace{\mathrm{H_2O}} & \overbrace{\mathrm{H_2O}} & \overbrace{\mathrm{H_2O}} & \overbrace{\mathrm{H_2O}} & \mathrm{Zn}\\ - & +\;\;- & +\;\;- & +\;\;- & +\;\;- & +\;\;- & +\end{array}$$

$$\left.\begin{array}{c}\textit{During}\text{ the}\\ \text{current.}\end{array}\right\}\begin{array}{cccccc}\overbrace{\mathrm{CuH_2}} & \overbrace{\mathrm{OH_2}} & \overbrace{\mathrm{OH_2}} & \overbrace{\mathrm{OH_2}} & \overbrace{\mathrm{OH_2}} & \overbrace{\mathrm{OZn}}\\ -\;+ & -\;+ & -\;+ & -\;+ & -\;+ & -\;+\end{array}$$

The *chemical affinity* of the *copper* for the hydrogen being exceedingly *feeble*, it escapes in bubbles of gas; but that of the *oxygen* for the *zinc* being very *powerful*, they combine, chemically forming *zinc oxide*, which, immediately being dissolved from the surface of the zinc (otherwise all electric action would cease) by the dilute *sulphuric acid*, forms *zinc sulphate*, $ZnSO_4$.

Thus the zinc and dilute sulphuric acid yield *zinc sulphate* and *hydrogen* gas, as expressed by the following formula:-

$$Zn + H_2SO_4 = ZnSO_4 + H_2.$$

For further illustration of the *molecular* changes set up by the Voltaic current, see Art. 240.

210. Sulzer's Experiment.—Place a piece of *zinc* in the mouth, so as to rest on the tongue, and a silver coin below the tongue. On bringing the edges of the two metals into *contact*, a peculiar but distinct taste will be produced. If in a perfectly dark room, the zinc be placed under the tongue, and the silver coin in the right place between the gum and the cheek, the nervous system being in a sufficiently sensitive state, a feeble flash of light will be perceived.

211. The Voltaic Pile, so called because of its *columnar* arrangement, was the earliest form of *battery* invented by Volta, after whom it is named. It consists (see fig. 123) of a series of pairs of *copper* and *zinc* discs arranged alternately, with layers of *flannel* or *cloth* saturated with very dilute acid, or a solution of common salt, the whole being uniformly arranged, beginning with the copper as the lower plate, and terminating with the zinc for upper plate, thus: copper, zinc, flannel—copper, zinc, flannel—through the entire series. The discs are usually retained in their places by means of vertical rods of glass.

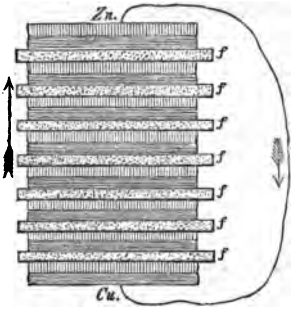


Fig. 123.—Voltaic Pile.

Cu, Copper plate.
Zn, Zinc plate.
f, Layer of cloth or flannel saturated with dilute acid.

The arrows show the direction of the *positive* current through the battery and connecting *wire*.

The copper and zinc discs are usually *soldered* together to ensure more perfect *contact.* Volta attributed the electricity thus developed to the *contact* of the two *dissimilar* metals, and regarded the moistened cloth as a mere *conductor.* The action of a large Voltaic pile, at first powerful, or even *violent,* quickly subsides to that of comparative feebleness, in consequence of the acid being squeezed from between the plates.

By means of a pile, consisting of a large number of these *couples,* Volta succeeded in giving electric *shocks,* producing *sparks* between two pieces of *charcoal* attached to the ends of the wires joining the *terminal* plates, making the gold leaves of an electroscope *diverge,* and producing other effects which were then regarded as of a startling character.

212. The Crown of Cups (Couronne des Tasses) was the second form of *battery* constructed by Volta, so called

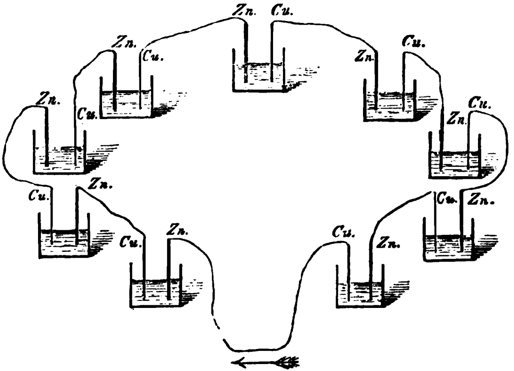


Fig. 124.—Volta's Crown of Cups.

Cu, Copper plate. } Immersed in glass vessel containing dilute
Zn, Zinc plate. } sulphuric acid.

The copper and zinc plates are arranged alternately, so that the *copper* plate in the one vessel is connected by a *wire* with the *zinc* plate of the *next* vessel on the *one* side, and *its zinc* plate is connected with the *copper* plate of the *next* vessel on the *other* side of it. When the *circuit is closed,* the *terminal* zinc and copper plates are united by their respective connecting wires.

because of its arrangement bearing a fancied resemblance to a royal *crown.* It consisted of a series of plates of *copper* and *zinc* immersed in dilute acid, contained in a series of glass cups or cells arranged in a circle, as shown in fig. 124.

The *chemical* and *Voltaic* actions of the *crown of cups battery* are precisely similar to those of the *Voltaic pile* and other *single-fluid* copper and zinc batteries described in this chapter. It possesses the great advantage over the *Voltaic pile* of continuing in comparatively uniform action for some time, in consequence of its abundant supply of the exciting liquid, which is not rapidly squeezed from between the plates by *gravity*, as in the case of the *pile.*

213. De Luc's Dry Pile consists, as improved by Zamboni, of a series of several hundred circular discs of paper, covered on one side with exceedingly thin *zinc* or *tin*-foil, and on the other with a rubbing of *peroxide of manganese*, the whole being enclosed in a glass tube terminated with metal caps.

With a *dry pile* of this construction, consisting of 2000 to 20,000 of these discs, electric bells may be rung continuously for months together, electric sparks produced, Leyden jars charged, chemical decomposition effected, and many other striking phenomena produced.

The dry pile is kept in action by its *hygrometric* condition, which depends on that of the atmosphere in contact with it. If one of the metal caps of the pile be placed on the *disc* of one *sensitive* gold-leaf electroscope, and the other cap on a second electroscope, the gold leaves of the *two* electroscopes will *diverge*, the one in connection with the *manganese* end of the *pile* with *positive*, and that in connection with its *zinc* end with *negative* electricity.

214. Bohnenberger's Electroscope, which is one of the most *sensitive* forms of electroscope, consists of a *single* insulated gold leaf suspended between two metallic plates or cheeks, which are in *electrical communication* with the two ends or poles of a *dry pile.* In its *normal* or *neutral* state the gold leaf hangs *vertically* between the two metal cheeks. When the gold leaf becomes *charged* with electricity from the body to be tested, it, if *positive*, is simultaneously *repelled* from the *positive* pole of the dry pile, and *attracted* by its *negative* pole. Fig. 125 shows the action of this electroscope when charged with *negative* electricity. The *construction* of the instrument will be readily understood from the figure.

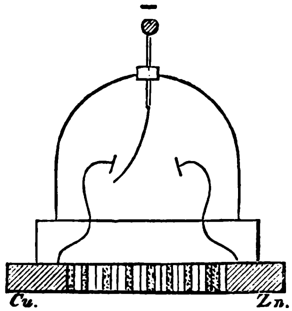


Fig. 125.—Bohnenberger's Electroscope.

Consisting of single gold leaf (insulated and protected as in common electroscope), hung *midway* between two *metal* plates connected by wires with the *copper* (Cu) and *zinc* (Zn) caps at the ends of the *Dry Electric Pile.*

215. Positive and Negative Currents of Voltaic Electricity.—The electricity of the current *which*, as previously described, leaves the *Voltaic cell* by the wire connected with the *copper* plate, possesses in a *feeble* degree the *qualities* of the *positive* electricity of the *glass* plate of the electrical machine. This current is therefore described as a current of *positive* electricity.

The electricity of the current which *leaves* the *galvanic couple* by the wire connected with the zinc plate, being in like manner similar, though much feebler, to that of rubbed *sealing-wax*, forms the *negative* current.

Experimental Proof.—Connect the *prime conductor* of a plate electrical machine by means of a metallic wire with one end of the coil of a multiplying galvanometer; also similarly connect the other end of the coil with the *rubber* of the machine, or with the *earth.* On working the machine, the galvanometer needle (see Art. 240) will be *deflected* in the *same direction* as that in which the needle is deflected by a working Voltaic battery, whose *terminal copper* plate is afterwards connected with the *same end* of the galvanometer coil as was the prime conductor, and whose *terminal zinc* plate is connected with the same end of the coil as was the rubber of the machine or the earth. Thus proving conclusively that the *same* kind of electricity passes out of the wire connected with the terminal *copper* or *platinum* plate of a working Voltaic battery, as is generated by the *glass* plate of an electrical machine.

To prevent the ambiguity and confusion which would otherwise arise from the use of the term "*current of electricity,*" electricians have agreed, unless otherwise expressed, to ignore the *negative current,* so that by the term *current of electricity,* unless specially described, is to be understood simply a current of *positive* electricity.

216. Experimental Proof of the Separation of the Two Kinds of Electricity by an Ordinary Voltaic Couple.—Connect the wire proceeding from the *copper* plate of a Voltaic pair with one *disc* of an *electric condenser,* and that proceeding from the *zinc* plate with the

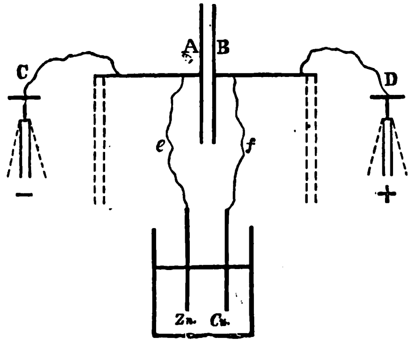


Fig. 126.—Proof of Separation of Opposite Electricities by Voltaic Couple.

A, Metallic disc of electric condenser connected by wire (*e*) with *zinc* plate of Voltaic cell; also connected by second wire with gold-leaf electroscope (C).
B, Disc of condenser similarly connected with *copper* plate of Voltaic cell by wire (*f*), and with electroscope (D).
Zn, Zinc plate of Voltaic cell.
Cu, Copper plate of Voltaic cell.

In this case electricity, collecting in the poles, acquires a feeble *tension* and becomes *statical.*

other *disc* of the *condenser* (as shown in fig. 126). The two *discs* being in close *proximity*, and *each* being in metallic connection with a delicate *gold-leaf electroscope*, are to be *momentarily* connected. The discs of the *condenser* (after being disconnected with the *cell*) may now be drawn away from each other, on which the gold leaves of the electroscopes (if sufficiently sensitive) will immediately *diverge* —those previously in connection with the *copper* charged with *positive*, and those with the *zinc* with *negative*, electricity.

217.* Polarization of the Plates of Single-Fluid Batteries.—Constant Batteries.—When a *single-liquid* battery has been at work but a short time its energy quickly falls, in a much greater degree than is due to the slight chemical exhaustion of its exciting fluid.

This is due to *two* causes jointly:—(1) A large portion of the *hydrogen* gas, liberated at the surface of the *negative* plate, clings to it, the bubbles liberating themselves very slowly: thus a large portion of the plate is put out of action by non-contact with its exciting fluid, due to the intervening *film* of gas. (2) The liberated gas being a *positive*, and the substance of the plate at which it is delivered a *negative* body, thus tend to form a secondary Voltaic couple, and set up a *counter* current, by which the original battery current is proportionally weakened.

This may be partially prevented by frequently brushing off the hydrogen from the zinc-plate with a soft brush; by *roughening* the *negative* plate with fine points, as in Smee's cells; or even by *violently shaking* the battery. The obnoxious hydrogen is, however, more completely got rid of by the use of a *second* fluid which *absorbs* the hydrogen; the battery is then termed a *constant battery*. The most popular of the constant batteries are the Daniell's, Grove's, and Bunsen's.

218.* A Smee's Element consists of a plate of *zinc* coupled with a *negative* plate of thin *silver* covered with a deposit of *platinum* in a minute state of division. The exciting fluid is dilute sulphuric acid. The microscopic roughnesses of the platinum surface facilitate the escape of the hydrogen.

219. Daniell's Couple, the most useful of the *constant* elements, consists of a *positive* plate of amalgamated *zinc*, immersed in dilute sulphuric acid, contained in a *porous cell,* which is placed in a concentrated solution of *copper sulphate,* either contained in a *copper cell* or a glass vessel enclosing a cylindrical copper plate. The *porous* cell or diaphragm *permits* of the passage of the electric current, but to a great extent *prevents* the mixing of the liquids. Its general form and construction is sufficiently shown in figs. 127, 128.

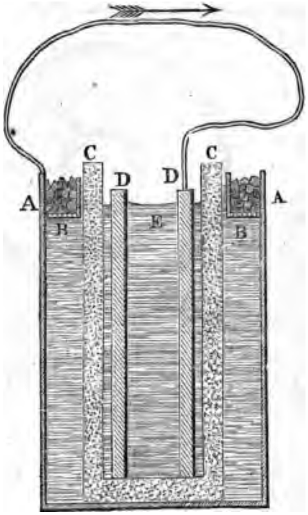


Fig. 127.—VERTICAL SECTION OF A CHARGED DANIELL'S ELEMENT.

A A, Cylindrical *copper* vessel forming *negative* plate of couple.
BB, Solution and crystals of copper sulphate on shelf.
CC, Porous vessel containing dilute sulphuric acid.
DD, Cylinder of *zinc.*
E, Dilute sulphuric acid.

220. Theory of the Action of a Daniell's Element.—The chemical action of the dilute sulphuric acid in the Daniell's cell, is similar to that already explained (see Art. 209), as taking place in the *single* liquid batteries. The molecule of hydrogen liberated, having traversed the *wall* of the *porous cell,* however, reacts on the *copper sulphate,* decomposing it, and causing a molecule of copper to be *deposited* on the copper (negative) plate for each molecule (double atom) of hydrogen set free, the latter immediately combining with the SO_4, and thus taking the place of the copper *deposited.* In other words, practically speaking, the hydrogen is *absorbed* by the copper solution, and thus prevented from *polarizing* the *negative* plate.

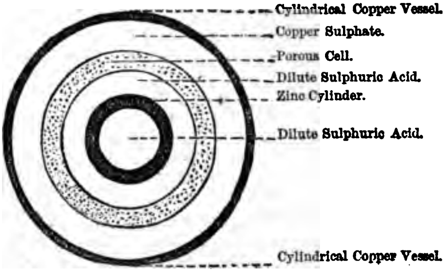


Fig. 128.—HORIZONTAL SECTION OF A CHARGED DANIELL'S ELEMENT.

The following equation shows the *chemical* and *molecular* changes set up during the working of a Daniell's Element—

Previous to current. *During* current.

$$Zn + H_2SO_4 + CuSO_4 = ZnSO_4 + H_2SO_4 + Cu.$$

221. A Grove's Cell or Couple is a *two-liquid* cell, in which the *exciting* liquid is dilute *sulphuric acid*, and the

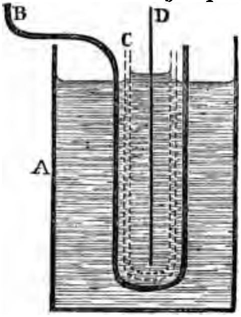


Fig. 129.—VERTICAL SECTION OF A GROVE'S CELL.

A, Flat-sided trough.
B, Zinc plate.
C, Flat porous cell.
D, Platinum plate.

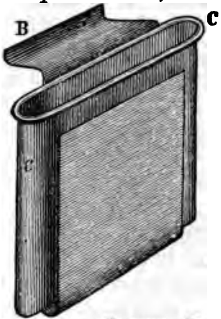


Fig. 130. — SHOWS POROUS CELL AND AMALGAMATED ZINC PLATE IN POSITION.

B, Zinc plate.
C, Flat porous cell.

anti-polarizing liquid is strong *nitric acid*, and *zinc* being used for the *positive*, and *platinum* for the *negative* plate. It consists, as shown in fig. 129, of an *external* cell of glass, porcelain, gutta-percha, or other *non-conducting* substance, containing dilute sulphuric acid, in which is placed a bent sheet of *amalgamated zinc*, folded round a flat *porous* cell, containing *strong nitric acid*, in the middle of which is placed the *negative* plate, consisting of a thin sheet of *platinum*. The connecting wires are fastened to the ends of the *zinc* and *platinum* plates by means of binding screws. The sulphuric acid should, for ordinary work, be diluted with ten times its bulk of water.

222. The Bunsen's Cell, or Battery is identical in principle and action with that of Grove: it differs from it only in using a cylinder or plate of *carbon* in place of *platinum* for the *negative* plate. (See fig. 131.) The original cost of the *Grove's* is greater than that of the

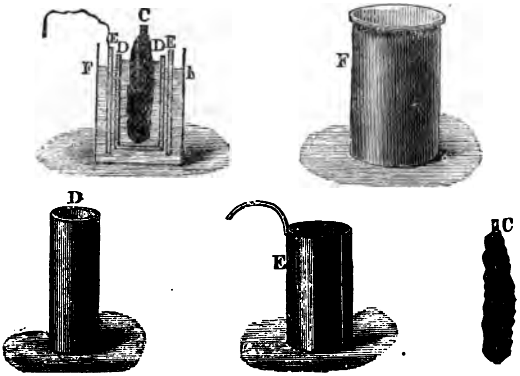


Fig. 131.—VERTICAL SECTION OF A BUNSEN'S CELL.
C, Carbon cylinder.
DD, Porous cell containing strong *nitric acid*.
EE, Zinc plate.
FF, Circular glass vessel containing dilute *sulphuric acid*.

Bunsen's battery; but it is said the cost of *working* of the Bunsen's is greater than that of the Grove's. Judging, however, from the conflicting statements of various experimentalists, with respect to the use of these batteries, it would appear that the relative cost and special advantages of these batteries are still matters of opinion.

223. Theory of the Action of a Grove's and a Bunsen's Element.—The action of the acid in this case also is precisely similar to that of the cases previously mentioned. But the *hydrogen* is prevented from *polarizing* the *negative* plate by its *absorption* by the *nitric acid,* which *it* decomposes by removing a part of its *oxygen,* thus forming water, *nitric acid* itself being converted into *hyponitrous acid, water,* and *nitrous acid,* copious, dense, red, irritating fumes of the latter being evolved from the working battery, which form a serious practical objection to its general use.

The following equation shows the general nature of the *chemical* and *molecular* changes set up in the interior of the cell during the working of a Grove's, or a Bunsen's couple, or battery:—

Previous to current. *During* current.

$$Zn+H_2SO_4+N_2O_5,\mathit{H_2O} = ZnSO_4+2H_2O+2\mathbf{NO_2};^*$$

Or,

$$Zn+H_2SO_4+2HNO_3 = ZnSO_4+2H_2O+2\mathbf{NO_2}.^*$$

These changes, however, vary with the strength of the nitric acid and period during which the battery has been at work.

224. A Voltaic or Galvanic Pair, Couple, or Element consists of two *dissimilar* metals in *direct contact* with each other, *united* by means of a *metallic* connection, the dissimilar metals being *immersed* in a liquid conductor (a *chemical* compound) which is capable of acting *more powerfully* on *one* metal than on the *other.*

225. A Voltaic or Galvanic Battery consists of a combination of a series of *Voltaic pairs* or *elements.* When they are arranged so that the *copper* or *platinum*

---

* Liberated as *noxious* red fumes.

(the negative) and the *zinc* (positive) plates are alternately joined to each other, the *electro-motive force* of the battery, due to the *number* of metallic plates introduced, *increases* in a greater ratio than the *resistance* of the liquid portion of the battery. This arrangement in the technical language of the telegraphist is designated as "*in series*," or as "*intensity arrangement.*" When *all* the *platinum* plates are connected together so as to act as one *large* plate, and all the *zinc* plates are *similarly* connected, and the two sets are united by two connecting wires as in the case of a *single* Voltaic cell, the arrangement is technically described as the "*quantity arrangement.*" In this case the "*quantity*" of electricity varies as the total *surface* of the plates joined together. But the "*electro-motive force*" remains the same.

The following diagrams, figs. 132 and 133, illustrate the construction of a Daniell's and a Grove's *battery.*

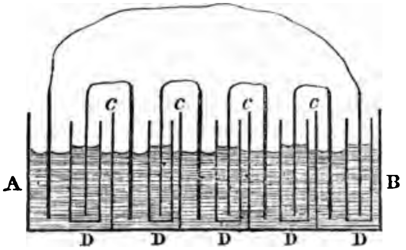


Fig. 132.—Daniell's Battery as arranged in Telegraphy.

A, B, Glass or gutta-percha trough containing 5 cells.
C, Partition dividing trough in cells.
D, Single cell containing one Daniell's couple.

226. A Grove's Battery consists of a series of cells united into one series, as shown in fig. 133, by suitable binding screws, the *zinc* in the one cell being united to the *platinum* of the next; and so on through the entire series. On the whole, perhaps the *Grove's* is the most economical, convenient, and powerful of the *two-liquid* batteries where a high degree of *intensity* is required. Its great objection, however, is its evolution of poisonous, irritating, *nitrous* fumes, which, however, may be greatly reduced by mixing *potasium bichromate* with the nitric acid.

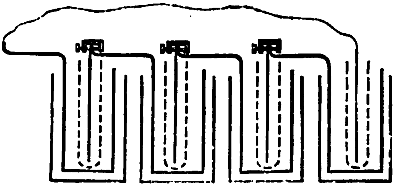


Fig. 133.—PLAN OF A GROVE'S BATTERY.

Showing the mode in which the Platinum and Zinc Plates are connected together, with binding screws, in the common or *intensity series* arrangement.

227. Electro-motive Series.—The electro-motive force of a *Voltaic couple*, developed by the chemical action of the liquid on the *positive* plate (the plate on which the *acid* or other exciting fluid acts most powerfully) is *greater*, the greater the difference between the chemical action of the exciting liquid on the one plate as compared with the other. Thus, if the *Voltaic couple* consists of an *iron* and a *zinc* plate, excited by dilute *sulphuric acid* (which readily acts on both metals in their ordinary state of purity as prepared commercially), the *electro-motive force* will be very *feeble*, and the current consequently of very *low tension.* But if a *platinum* plate, on which dilute sulphuric acid exerts no sensible *chemical* action, be substituted for the *iron* plate of the *couple* (the *platinum* thus becoming the *negative* plate), and the *zinc* plate being retained as the *positive* plate, the *electro-motive force* will be very greatly increased, the *tension* of the electric current being correspondingly raised.

When a number of metals or other conductors are arranged in the order in which, when placed in *Voltaic couples*, the greater the distance between any two of these bodies the greater the *electro-motive force* developed, they are described as constituting an *electro-motive series.*

In the following list, those bodies which are placed at or towards the *top* of the series are *electro-positive* to those *below* them, those below, as a matter of course, being *electro-negative* to those above them. And the greater the distance on the list between any two bodies, that is, the nearer the one is to the top of the list, and the other to the bottom, the *greater* the electro-motive force generated in *Voltaic couple*, and the greater the efficiency of the *couple* into which they enter. Thus in the following series *zinc* and *cadmium* (excited by dilute sulphuric acid) would constitute a very feeble, and *zinc* and *graphite* a comparatively powerful current.

ELECTRO-MOTIVE SERIES, THE EXCITING LIQUID BEING DILUTE SULPHURIC ACID.

+ Zinc.
Cadmium.
Tin.
Lead.
Iron.
Nickel.
Bismuth.
Antimony.
Copper.
Silver.
Gold.
Platinum.
– Graphite

If some other exciting fluid, as solution of *caustic potash*, or *potassium sulphide*, were employed, the following order would in some cases be reversed from reasons just explained.

228. Electro-motive Force is the force by which *electrical separation* is effected, or which causes or tends to cause a *transfer* of electricity.

It is thus the immediate force that produces the electric *current*, which gives rise to electric *tension*, and which produces *difference* of electric potential. It may be originated by friction, by heat, chemical action, or even by the inductive influence of an adjacent current.

229. The Electro-motive Force of a Voltaic Pair or Battery is "that quality of the *pair* or *battery* in virtue of which it tends to do work by the *transfer* of electricity from one point to another." In other words, the electromotive force of the battery is the force with which it sets up the process of the *separation* of the electric fluids, and consequently establishes *electrical currents.* The *greater* the electro-motive force of the battery the greater the *resistance* capable of being overcome by the *electric current* issuing from it.

The *electro-motive force* of a Voltaic pair depends, other conditions being equal, upon the *difference* of the chemical affinity of the two metals in *contact* for the active element of the exciting liquid. The more the acid or other exciting liquid tends to act on the one metal, say the zinc, as compared with its tendency to act on the copper, the *greater* the *electro-motive force* of the Voltaic pair; because the acid would tend to act still *less* on *platinum* than *copper*, the electro-motive *force* of a *platinum* and *zinc* pair would be *greater* than a *copper* and *zinc* pair. From what has just been stated, it must also follow that the electro-motive force of a Voltaic couple must also vary with the nature of the exciting liquid.

230. The Chief Sources of Electro-motive Force are:

1. Mechanical action (friction, compression, disruption, concussion, etc.
2. Chemical action.
3. Physical action (heat, crystallization, change of physical condition).
4. Electricity in motion.
5. The action of Magnets.

Friction charges a small body with a small charge of *high potential. Chemical* action almost instantaneously charges a large body with a large charge of electricity of *low potential,* such potential, however, being the *maximum* it can produce.

231. Intensity or Strength of Current, Ohm's Law. —By intensity or strength of the current is meant the quantity of electricity passing in any given unit of time.

The following important law, which lies at the base of successful and economical telegraphy, was discovered by Ohm. "The *intensity* of the current is equal to the *electro-motive force* divided by the *resistance* " Or,

$$I=\frac{E}{R}$$

232.*Electric Potential, which may be popularly interpreted as *electric level,* is essentially a *ratio.* It holds the same relation to electricity that the term *level* does to *gravity;* and just as water at a *higher level* tends to flow to a *lower* one, so electricity at a *higher potential* tends to flow to a point at a *lower potential.*

Difference of potential is therefore that "difference of *electrical condition* which determines the direction of the transfer of electricity from one point to another." The *potential* of the earth is taken as *zero.*

233. Electrolysis is the process by which a compound liquid (termed an *electrolyte*), a *conductor* of electricity, is *chemically* decomposed by the passage through it of a current of electricity.

Thus, if a current of electricity be passed through, say, acidulated *water,* it is decomposed into its constituents *oxygen* and *hydrogen;* if through *hydrochloric acid,* into *chlorine* and *hydrogen;* if through *potassium iodide,* into *iodine* and *potassium.* In each of these cases the molecules become *polarised,* the terminal particles of the compound series, say the *water,* splitting off—the *electro-negative* molecule, the *oxygen,* going to the *positive* electrode, and the *electro-positive* molecule, the *hydrogen,* going to the *negative* electrode.

For electrolysis of water, see next Article. The following diagram (fig. 134) illustrates an arrangement by

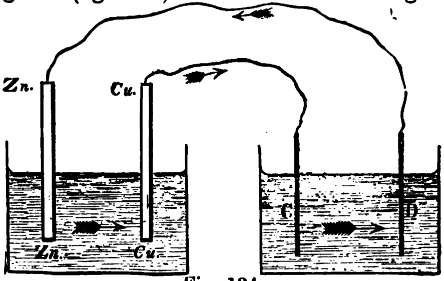


Fig. 134.

VOLTAIC BATTERY AT WORK.

DEPOSITING CELL containing solution of cupric sulphate.
C, Positive electrode.
D, Negative electrode.

which metallic salts may be *electrolysed* (decomposed by the Voltaic current), so that the metal may be deposited as a *solid* on the surface of the *negative* electrode, or the *cathode.* Modifications of this plan are adopted in the various processes of *electro-typing*, electro-plating, electro-gilding, etc. (see Arts. 255-259).

According to this arrangement (fig. 134), a Voltaic current, generated by the action of dilute sulphuric acid on a copper-zinc cell, is transmitted through an electrolysis (depositing) cell containing two copper plates (the electrodes) immersed in a solution of cupric sulphate ($CuSO_4$). The molecules of the cupric sulphate becoming first *polarised* are then decomposed (electrolysed), dilute sulphuric acid in the liquid state appearing at the surface of the *positive* plate, and *metallic copper* being *deposited* upon, and becoming adherent to, the *positive* plate as follows:—

Before passage of current.* $+\mathbf{Cu}+CuSO_4+SO_4Cu+CuSO_4+\mathbf{Cu}-$

During passage of current. $+\mathbf{Cu}+SO_4+SO_4Cu+SO_4Cu+Cu+\mathbf{Cu}-$

Many experiments in electrolysis, as the decomposition of sodic or potassic sulphate, potassium iodide, etc., may be best performed by inserting the electrodes in the opposite ends of U tubes containing solutions of the salts to be decomposed, mixed with red litmus, or in the case of potassium iodide with starch. (See Art. 40, Appendix.)

234. The Voltameter, invented by Faraday, is an instrument by which the *strength of the current* is *measured* by the quantity of water decomposed in any given *unit* of time. It is found that if a current of Voltaic electricity be passed through a circuit, including a *tangent galvanometer* and a *Voltameter*, that the quantity of the mixed gases (oxygen and hydrogen) evolved in any given time is proportional to the tangent of the angle of deflection of the needle. (See Art. 11, Appendix.)

The Voltameter consists (as shown in fig. 135) of two *glass tubes* (*a b*) inverted over two platinum plates or *electrodes*, supported by the *glass trough* (*c*), through the bottom of which wires pass from the platinum plates to two binding screws fixed in the wooden base (*d*). On connecting the platinum electrodes with the *battery at work* by means of the binding screws, the trough and graduated tubes being charged with *acidulated* water, the molecules of the *water* through which the Voltaic current passes become *polarised*, the terminal molecules of the *electro-negative* oxygen being liberated as gas at the +pole, or *anode*, and the terminal molecules of the *electro-positive* hydrogen being liberated in contact with the – pole, or *cathode*. The *hydrogen* thus liberated occupies twice the cubical space of the *oxygen*.

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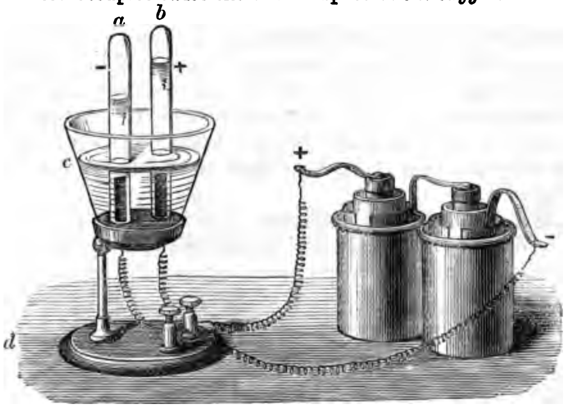
* The thick type symbols represent the copper electrodes.



Faraday's Voltameter. **Daniell's Battery.**

Fig. 135.—SHOWING ELECTROLYSIS OF WATER.

a b, Two glass tubes, charged with dilute sulphuric acid, standing over platinum *electrodes*.

c, Glass trough, containing dilute sulphuric acid, and supporting electrodes.

d, Wooden base, with binding screws, for connecting *electrodes* with Voltaic battery.

The supposed *chemical* and *molecular* changes set up in the acidulated water during the action of the *Voltaic current* are illustrated by the following diagram:—

Before current, $\overbrace{H_2O}\ \overbrace{H_2O}\ \overbrace{H_2O}\ \overbrace{H_2O}$

During current, $+\mathbf{H_2}\ \overbrace{OH_2}\ \overbrace{OH_2}\ \overbrace{OH_2}\ \mathbf{O}-$

235. The Circuit is the *path* traversed by the electric current. Thus the *circuit* ordinarily includes the *zinc* plate, the battery *liquid*, the *connecting* wires, and the *copper* plate; also any *liquid* or other *object* interposed between the *terminals* of the connecting wires *through* which the current *passes*. When the Voltaic current is *arrested* by the disconnection of the wires or other media through which it passes, the *circuit* is said to be *opened* or *broken*. When the connections are again established, the *circuit* is said to be *completed* or *closed*.

236. The Poles or **Electrodes** are the ends of the wires or the surfaces of the plates by which the electric current *enters* and *leaves* the liquid or other substance submitted to its action. The *positive* pole or *anode* is the *surface* or plate at which the *positive* current *enters*, and the *negative* pole or *cathode* that at which it *leaves* the substance.

237. Ions, Anions, Cations.—Liquids, excepting *mercury*, do not *conduct* electricity after the manner of solids. Among liquids in general, only compounds termed *electrolytes* (see Art. 233) permit of the passage of electricity, and they permit of such passage in the ratio in which they are split up (chemically decomposed) into their constituent *elements*, such elements transferring the electricity, as it were, by *convection* as they are liberated at the respective *electrodes* of the battery.

The *elements* thus liberated at the *poles* by the decomposition of an *electrolyte* are designated *Ions* (from Gr. *hodos*, a way or path).

The *Ion*, liberated at the *Anode* or *positive* pole, that is which is *liberated* at the point at which the electricity *enters* the liquid (electrolyte), is termed the *Anion*.

The *Ion*, liberated at the *Cathode* or *negative* pole, that is the point at which the electricity *leaves* the liquid, is termed the *Cation*.

238. Oersted's Compass Needle Experiment.—Oërsted discovered the *directive* action of an electric current on a *magnetized* needle, and thus blended electricity and magnetism into one science. (1) Support a *horizontal* compass needle so that it may move freely on a *vertical* point. (2) Place a wire immediately *over* or *under*, but *parallel* with, the needle: no effect is produced. (3) Now, pass a Voltaic current through the wire, the *north* end of the needle will be immediately *deflected* to the *right* or to the *left*, according as the current is passing from *north* to *south*, or *south* to *north*, or as it is *above* or *below* the needle (see figs. 136, 137).

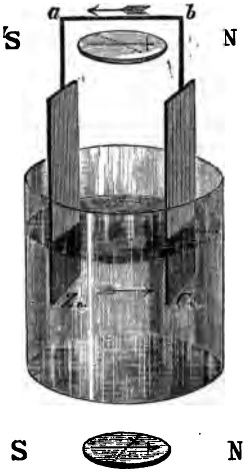


Fig. 136.—Showing Direction in which Compass Needle is Deflected by Voltaic Current passing above and below Needle.

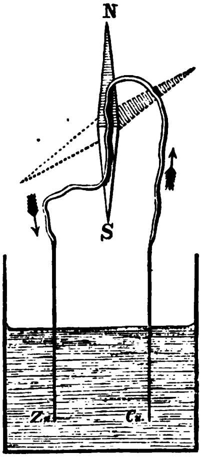


Fig. 137.—Showing Deflection of Vertical Magnetized Needle by Voltaic Current.

There are thus *four* cases of *deflection* of the compass needle by an electric current with which the student should make himself familiar:—

When the current passes *above* the needle.	1. If from north to south, the marked end turns to the *east.* 2. If from south to north, the marked end turns to the *west.*
When the current passes *below* the needle.	1. If from *north* to *south,* the marked end turns to the *west.* 2. If from *south* to *north,* the marked end turns to the *east.*

Memory Rule for ascertaining the Direction in which an Electric Current will Deflect the North Pole of a Magnetized Needle, and the End of the Coil at which the North Pole of a Bar Magnet will be formed.

Let the observer imagine himself to be *swimming with* the current, his *face* turned *towards* the *needle* to be *deflected,* or the *bar* to be *magnetized* (see figs. 14, 15), the current thus flowing from his feet *towards* his head—the *north pole* of the *compass needle* will be *deflected* to his *left,* or the *north pole* of the *bar* will always be formed at the *end of the coil,* which is on his *left.*

239. An Astatic Needle (from Gr. *a,* not; *statikos,* causing to stand) is a compound *magnetized* needle, over which the earth has lost its *directive* power, and which will therefore, as its name implies, *stand* or remain at *rest* in any position altogether independent of the magnetic meridian (see fig. 119).

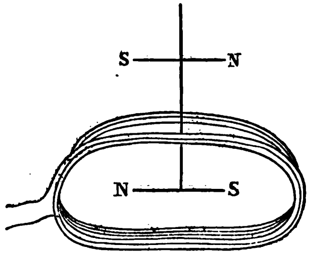


Fig. 138.—Astatic Needle.

It is formed by connecting two magnetized needles of *equal* power by a central pin, so that the *north* pole of the one is fixed directly *over* the *south* pole of the other, also its *south* pole directly *over* the *north* pole of the needle below. By this arrangement, which, however, can rarely be made perfect, the *directive* power of the earth must manifestly be entirely overcome; since in whatsoever direction the *upper* needle tends to turn *under* the magnetic influence of the *earth,* the lower needle tends to turn with *equal* force in the *opposite* direction. In this manner its *sensitiveness* to the action of the electric current is greatly increased.

240.* The Multiplier or Galvanometer is an instrument used to measure the strength of current electricity by the degree to which it *deflects* the compass needle, as measured on a circular card graduated into degrees (see fig. 139).

It consists essentially of a coil or helix of silk or cotton-covered insulated copper wire, in the middle of which is suspended a *magnetized* needle, so placed that on sending the *current* through the coil it passes directly *above* and below the needle, thus *deflecting* it to the one side or to the other, according to its *direction*, and to a degree depending upon, though not proportional to, its *strength*. The *sensitiveness* of the instrument is greatly increased by the use of an *astatic* needle. Its sensitiveness is also increased within certain limits by increasing (*multiplying*) the number of turns of the coil; hence its name.

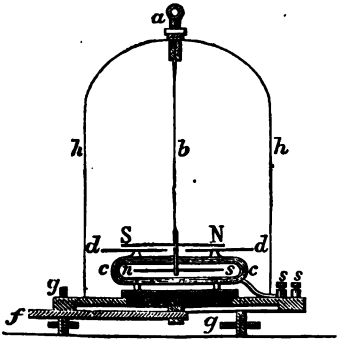


Fig. 139.—ASTATIC GALVANOMETER OR MULTIPLIER (Vertical Section).

a, Screw for raising or lowering Astatic needle.
b, Fibre of raw silk.
c, Insulated copper wire coil connected with binding screws.
d, Graduated circular card attached to coil.
N S, *ns*, Astatic needle.
e, Circular *movable* block to which coil is fixed.
f, Lever for bringing the *zeroes* of circular card under ends of needle, and thus bringing coil and needle into *parallelism*.
g, Tripod screws for *levelling* instrument.
h, Glass shade.
ss, Binding screws for connecting *coil* with battery.

241. Abnormally Active condition of connecting Wires of Voltaic Couple at Work.—If the connecting-wires joining the two plates of a Voltaic couple be immersed in *iron filings,* they will be attracted by the wire as by a magnet; if placed *above* or *below,* but *parallel* to a compass needle, they will *deflect* it; if a short *fine* wire be inserted between the ends of connecting wires it will become very *hot,* even to the extent of becoming *luminous.* The ends of the wire will also emit feeble *sparks* on contacts being made and broken. To the *physical cause* of the condition of the wire, by means of which these and other effects are produced, the term *electric current* is applied.

A metallic wire or conductor through which an electric current is flowing thus becomes an active agent, being able to set up various effects, calorific, chemical, magnetic, and physiological, with a degree of power and intensity proportionate to that of the current.

242. The Voltaic Current of Equal Strength through all parts of the Circuit.—If a *series* of *Voltameters* be introduced into various parts of the *circuit,* that is, both between the *terminals* of the battery and between the various *cells* themselves, *equal* quantities of the mixed gases will be given off in each case, thus proving the Voltaic current to be of equal strength throughout all parts of the same circuit.

Any obstruction caused by defect in one cell would thus be repeated in each cell all through the battery; that is, if in one cell an obstruction, shutting off three-fourths of the current traversing it, occurred, each of the other 99 cells would, in like manner, pass only one-fourth of its normal current.

243. The Chief Difference between Frictional and Voltaic Electricity consists in the fact, that the latter whose *electro-motive force* is so feeble as to render it incapable of overcoming a comparatively slight resistance, is generated in very *large quantities;* while the former, on the contrary, is generated in very *minute quantities,* but its *electro-motive force* is so great as to enable it readily to overcome *resistances* many millions of times as great as that which would entirely stop the passage of a current of Voltaic electricity.

Many of the more peculiar phenomena of Voltaic electricity are, however, exclusively due to its condition of *current* or *flow*.

Thus the principal phenomena of electro-magnetism, and of electro-dynamics, are due, *not* to the mere *presence* of electricity, however great its *tension*, but to its *state* of *current*, or *flow*. For instance, if the ends of the silk-covered copper wire (figs. 1, 14, and 15) were supported on glass legs, and the coil itself were charged with electricity in a state of *rest* (*statical electricity*), the soft iron bar or poker round which it is coiled would fail to become a *magnet*, or to display any of the phenomena of *magnetic polarity*, but would simply remain a mass of soft iron.

Again, if two pieces of *insulated* brass wire, suspended side by side by fibres of silk or glass, so as to be *parallel* to each other, were charged with *similar* electricity, both positively or both negatively, they would tend to *repel* each other. But if *two currents* of *similar* electricity, each positive, or each negative, were respectively transmitted through these wires so as to pass in the *same direction* through each, they would *attract* and *not repel* each other during the period of such electric passage.

244. A Porous Cell usually consists of an oval or a cylindrical vessel of baked, unglazed, and therefore *porous* clay or *biscuit ware;* but it may be constructed of brown paper (see Appendix) or other porous material, capable of withstanding the mixture of the two fluids in contact with its *exterior* and *interior* surfaces, at the same time that its *substance* shall become so charged with them by absorption as to permit of the establishment of a Voltaic current through the walls of the cell.

The *function* of the porous cell consists in its transmission of the *Voltaic current* by permitting of that state of *polarization* of the *molecules* of the liquid conductors being set up within its walls which is necessary to the transmission of the electric current, at the same time that it effectually prevents the *mixing* of the two fluids.

Fig. 141 illustrates the passage of an electric current consequent on the transmission of the *state of polarization* of the molecules of *hydrochloric acid* through the substance of a porous diaphragm to the molecules of the cuprous chloride. Each *molecule* of hydrochloric acid (symbol HCl) consists of one *atom* of hydrogen united to one *atom* of chlorine; and each *molecule* of cuprous chloride (CuCl) of one of copper and one of chlorine.

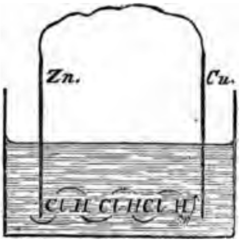


Fig. 140.—Showing Polarization of Molecules of Hydrochloric Acid in Working Voltaic Cell.

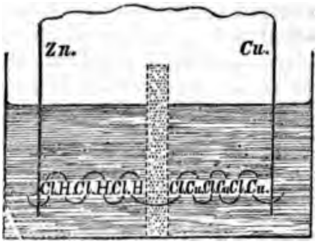


Fig. 141.—Showing Propagation of state of Polarization from Molecules of Hydrochloric Acid through Porous Diaphragm to Molecules of Cuprous Chloride.

All porous cells, however, present the serious disadvantage of increasing the *battery resistance* of the *circuit.* They also by *cracking*, and by their *pores* becoming more or less filled up with metallic or other deposit, tend to obstruct the efficient working of the battery. Accordingly it is a great desideratum, hitherto only partly achieved in certain cases, to construct batteries in which porous cells may be dispensed with.

245. Gravitation Batteries.—Attempts have been made to get rid of the defects arising from the obstruction, resistance, and cracking of *porous cells* in two-liquid batteries by placing the *copper* plate *horizontally* in the *lower* part of the vessel surrounded by the *heavier* cupric sulphate. The *zinc* plate in such batteries is placed *horizontally* above the copper plate. To charge the battery, the lower part of the vessel is filled with solution and *crystals* of sulphate of copper, after which the upper part containing the zinc plate is carefully filled with dilute sulphuric acid. These batteries derive their name from the fact that *gravity* plays the part of the *porous* cell in preventing the mixing of the two solutions. Gravitation batteries must, however, not be moved after being fully charged. But this difficulty may be partially met by partly filling them with *sawdust.*

246.* Polarization and Transfer of Elements (Migration of Ions).—The student will be careful to distinguish *polarization of the liquid* from *polarizaton of the plates* of the battery (see Art. 217). It has already been shown that, according to the generally accepted theory of Grotthus (Art. 234), the electricity which flows through the liquid portion of the circuit (*a*) sets up among its molecules a peculiar, orderly, and successive arrangement of its particles, in which all the *electro-positive* atoms are turned towards the *negative* plate, and the *electro-negative* atoms towards the *positive* plate; (*b*) sets up a series of *decompositions* and *recompositions* by which the *terminal* elements (ions) in the series are *liberated* in the state of solid liquid, or gas, at their respective poles.

In no case do the intermediate particles of the liquid electrolysed show any signs of chemical or physical change. And in all cases of such polarization, the *ions* behave as though they *travel with* the current, and are liberated at the surface of the electrode, at which the current *leaves* the liquid.

That this state of polarization, with its successive *de*compositions and *re*compositions, is the true exposition of the apparent transport of the *ions,* is rendered highly probable by the following experiments of Davy.

EXPERIMENT.—(*a.*) Place three shallow glass vessels in a row, nearly fill *middle* one with *ammonia,* the *first* with potassic sulphate, and the *last* with pure water.

(*b.*) Into the *first* vessel pass the *negative* electrode of a very powerful Voltaic battery, and into the *last* its *positive* pole; connect the first and second, and the second and third by means of fibres of linen or cotton (still better by fibres of asbestos) saturated with water.

(*c.*) Now pass a very powerful galvanic current through the fluids in three vessels. After a short time the water in contact with the *positive* pole in the third vessel will become *acidified* from the presence of *sulphuric acid,* which must have passed over from the potassic sulphate in the first vessel through the *ammonia* in the middle vessel; the contents of the first vessel in contact with the negative pole will have become *alkaline* from the separation of its *potassium.*

The liberated *ions* in many cases do not appear in the form in which they are liberated at the electrodes, but combining in their *nascent* state with one or more of the elements of the undecomposed liquid, they appear in the form of compounds. To such reactions the term *secondary action* is applied. Thus, when sodium sulphate is electrolysed, the sodium liberated at the negative pole takes an atom of oxygen from the water, and becomes Na_2O, and the radical sulphion (SO_4), the corresponding molecule of hydrogen becoming sulphuric acid (H_2SO_4).

This experiment may be modified by filling the *middle* glass with *syrup of violets,* through which the sulphuric acid from the potassic sulphate may be made by the current to pass into the third vessel without the syrup *reddening.*

247. The Exciting Fluid of a galvanic cell must consist of a chemical compound containing two or more chemical elements, one of which acts more powerfully on *one* of the *metal* plates of the Voltaic element than on the other. It must accordingly be capable of yielding up one of its elements to form a *soluble* compound with the substance of the *positive* plate, and must be sufficiently *diluted* with water to be able to *dissolve* away such compound as rapidly as it is formed. If *sulphuric acid* be used, it should be *diluted* with 7 to 12 times its bulk of *water,* so as to be able to retain the *zinc sulphate* formed by its action in a state of solution.

A solution of common salt, *sodium chloride* (NaCl), has the advantage, when used with a zinc and copper element, of generating electricity of sufficient electro-motive force for *compass needle* and for single cell *electrotype* experiments, without the disadvantage when spilt of spoiling the clothes, or the furniture, a merit which the parents of many young students will appreciate.

248. Local Action on Zinc Plates.—If *pure* zinc be immersed in dilute sulphuric acid, little or no action is excited, no zinc dissolved, no hydrogen evolved. If a piece of common, impure, *un*amalgamated zinc be immersed in the dilute acid, the zinc becomes quickly dissolved, hydrogen gas being rapidly disengaged. If a copper or platinum plate be now introduced into the liquid at the same time as the zinc, and the two plates be connected by an external wire, as in an ordinary galvanic pair, a portion of the hydrogen gas thus evolved will be transferred from the surface of the zinc to that of the platinum. In all probability, however, the larger part of the hydrogen thus liberated will still continue to be evolved at the surface of the zinc plate. All the hydrogen so liberated indicates so much waste action, and all the zinc consumed in producing it is so much zinc wasted without contributing anything to the working power of the battery, that is, to the strength of the electric current generated by it.

Such *waste* is said to be produced by *local action*. It is supposed to be set up by the minute particles of arsenic, cadmium, carbon, copper, iron, lead, tin, etc., which, as *impurities*, are found in a greater or less degree in all varieties of commercial zinc. These foreign metallic particles in contact with the zinc, and the exciting liquid, act as so many microscopic galvanic elements, which, setting up so many *local currents*, seriously waste the zinc, not only without contributing to the strength of the *general electric current* passing through the connecting wire, but in such a manner as to lessen its quantity or efficiency. Even *pure zinc* will set up this destructive *local* action when its parts are of *unequal* *hardness*, and therefore of unequal *solubility*, the *harder* parts acting as so many *negative*, and the *softer* as so many *positive* plates. These defects in the working of plates of common zinc may be corrected by the process of *amalgamation*. (See Art. 12, Appendix.)

249. Theory of the Action of Amalgamated Zinc.—When *mercury* (quicksilver) is rubbed over a clean surface of zinc it dissolves it, forming a solution of *pure* zinc in mercury (zinc amalgam), but it is incapable of dissolving, or equally dissolving the iron, copper, and most other impurities. The *zinc amalgam* thus diffused over the entire surface of the plate probably acts thus: (*a*) It, covering the surface of the zinc, interposes itself, to the exclusion of the exciting liquid, between the zinc and particle of iron or other impurity, and thus prevents local action. (*b*) It prevents the *harder* parts of the plate from becoming *negative* to the *softer* parts by covering its entire surface with a solution of pure zinc of *uniform consistence*, which is presented to and acted upon by the acid with equal readiness at all points at which the plate is brought into contact with it.

250.* The Electrical Resistance of a substance is that quality of the body by which it tends to *obstruct* or *retard* the flow of electricity, or the propagation of the *state of polarization* of its constituent molecules; and is such that if the length of the body be *doubled*, the resistance is *doubled*, or if *halved* the resistance is *halved*, and which is *lessened* as the *section* of the body through which it flows is *increased*, or is *increased* as the *section* of the conductor is *diminished*.

In a galvanic battery the current is limited by the fluid resistance of the battery, and this resistance is diminished exactly in the ratio in which the *distance* between the plates is *decreased*, and in that in which their *size* is *increased*.

To distinguish the *resistances* encountered by the electric current in various *parts* of the circuit from each other, that offered by the fluid in the *cell* is termed the *essential, internal*, or *battery resistance*, and that presented by the *conducting wire* or other medium connecting the two plates, the *external, interpolar*, or *non-essential resistance.*

The *resistance* of a body is the *reciprocal of its conductivity.* Electrical resistance is *measured* practically in *Ohms* or *British Association* (B. A.) *units*, by means of *known lengths* of German silver or platino-silver wire made into *resistance coils;* and also by means of the *rheostat, rheocord*, etc., constructed on similar principles.

251. Resistance converts Electricity into Heat—Heat increases Resistance in Wires of Circuit, as proved by the following experiments:—

Experiment I.—Pass current from battery of four or five Grove's cells, through *thick* iron wire, for a few seconds only, no appreciable *heat* is developed, because the *resistance* is unimportant.

Experiment II.—Separate the ends of the iron wires, and join by *very fine* iron wire three or four inches long. Again close circuit, the fine wire will become first *red*, and then, if *not* too long, *white* hot, ultimately fusing into small globules. The *smallness* of the section of the wire in this instance causes it to offer *great resistance*. Gunpowder may be *fired* by the *heat* thus generated.

Experiment III.—Repeat the last experiment, but making the fine iron wire so *long* as that, by its resistance, it shall only permit so much of the current to pass as shall heat the wire to *dull redness.* Now bend the thin wire into a curve, and dip the curve into a glass of *cold* water, the two ends of the fine wire, not immersed, will immediately become *white* hot. The *cooling* of the wire has thus *lessened* the *resistance* of the wire, so that *more* electricity passes in a given time.

Experiment IV.—Loop together *alternately* the ends of five or six pieces of fine *platinum* wire, about three-quarters of an inch long, with an equal number of similar pieces of *silver* wire. Introduce into circuit; pass current through in the dark. The *platinum* links of the chain will now become *incandescent*, while the *silver* links remain quite invisible. If a portion of the chain be immersed in cold water, the platinum links *not* immersed will become *brighter* for the reason just given. The *silver*, a *good* conductor, transmits without appreciable resistance all the electricity, the *platinum*, a much *inferior* conductor, allows to pass.

252. The Chemical Theory of Voltaic Electricity was originated by Fabroni, a fellow countryman of Volta, who observed the *chemical action* of the *acid* on the *zinc* discs of the Voltaic pile. To Faraday is due the discovery that the quantity of electricity developed is proportional to the chemical action of the exciting liquid on the *positive* plate of the Voltaic couple. The student may easily satisfy himself of the fact, that as the *chemical action* of the battery *rises* and *falls*, so does the *strength* of the current generated, by varying the strength of the exciting fluid of his cell. He may also repeat the following experiments:—

EXPERIMENT (*a*).—Connect the copper and the zinc plate of a small galvanic cell with a not too sensitive galvanometer by means of a *short, thick* copper wire.

(*b.*) Hold the two plates of the cell parallel, and very *near* together. Immerse the two plates to the depth of about one-eighth of an inch in the exciting liquid. (Solution of common salt will do.) Observe the deflection of the needle of the galvanometer.

(*c.*) Gradually *increase* the immersion of the plates until they are nearly covered. Observe that the deflection of the galvanometer needle increases with the amount of surface covered by the liquid.

(*d.*) Remove the plates *farther* apart, and observe as the *distance* between the plates *increases* that the deflection of the galvanometer needle *decreases.*

This experiment proves that the *quantity of electricity* circulating in the *connecting wire increases* or *decreases* with that of the *chemical action* in the Voltaic cell. It also proves that it increases or diminishes as the *resistance* due to the length of its journey through the liquid of the cell is increased or diminished by the *shortening* or *lengthening* of that journey. (See Art. 250.)

253. Volta's Experiment.—Volta having invented the *condensing electroscope,* devised the following experiment, on which he based his celebrated "*contact theory,*" afterwards generally discarded in favour of the "*chemical theory,*" but recently brought to the front again through the investigations of Sir W. Thomson:—

EXPERIMENT.—Volta constructed a *compound* bar, one-half of which was of copper, and the other of *zinc.* He then, holding the zinc end of the bar in one hand, brought the copper end of the bar into contact with the *under* surface of the disc or *collecting* plate of the electroscope, at the same time *touching* with the finger of the other hand the top of the *condensing* plate. He then *first* removed the compound bar from the *lower* disc, and *afterwards* the finger from the upper (condensing) plate, in neither instance did the gold leaves *diverge*. On now removing the upper plate, by means of its glass handle, the gold leaves of the electroscope immediately *diverged* with *positive* electricity derived from the *copper* of the bar.

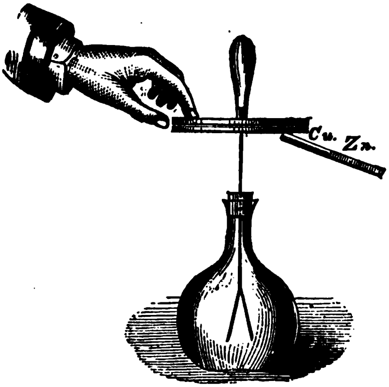


Fig. 142.—Volta's Experiment.

Volta's mode of testing electricity of *copper* end of compound bar of copper and zinc by means of his *condensing electroscope*.

254.* Volta's Contact Theory.—On the above experiment Volta based the following theory, viz.:—"*That when any two dissimilar substances are placed in contact, the one becomes positively and the other negatively electrified.*" This principle, if taken alone, as it was adopted by Volta himself, seems, however, entirely opposed to the doctrine of the *conservation of energy* at present unanimously adopted by physicists.

The exact relationship which the influence of *contact* of the plates of a galvanic element bears to that of the *chemical action* of the exciting fluid on the *positive* plate of the couple in the generation of the Voltaic current, forms one of the most interesting subjects of investigation of the present day. The following experiments tend to show that mere *contact* of dissimilar metals, unattended by chemical action, is of itself capable of producing electrical separation, or *difference of electric potential*, and consequently giving rise to electric *current*.

Experiment I.—Let a perfectly clean, bright, dry bar of *zinc* be placed end to end against a similar bar of copper (see fig. 143), *electrical separation* immediately takes place, the zinc becoming charged with *positive* and the copper with *negative* electricity. The electricity thus developed will, however, be of such *feeble tension* as to escape observation with instruments of only ordinary delicacy.

Fig. 143.—Copper and Zinc Bars illustrating supposed *contact origin* of electricity.

The following modification of this experiment will, however, render the development of electricity real or apparent by the *mere contact* of dissimilar metals more palpable.

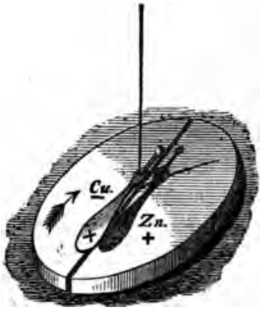


Fig. 144.—Showing Change of Electric Potential due to Contact of two Dissimilar Metals. Consists of a semicircular disc of *copper* in contact with a similar disc of *zinc*, above which is suspended, by means of a fine wire from the interior of a *positively charged* Leyden jar, a light *aluminium* needle.

Experiment II.—(*a.*) Place a semicircular disc of zinc in contact with a similar disc of copper (see fig. 144).

(*b.*) Suspend from the knob of an ordinary Leyden jar (the interior of which is charged with *positive* electricity) by means of a fine *metallic wire*, a light, *thin*, broad, flat aluminium needle.

Observe, as shown in the figure, that the aluminium needle, kept permanently charged with *positive* electricity by its connection with the interior of the Leyden jar, will permanently turn from the *zinc* to the copper, being *attracted* by the *negative* electricity of the *copper*, and *repelled* by the *positive* electricity of the *zinc*.

CHAPTER XII.

ELECTRO-METALLURGY—THE ELECTRIC TELEGRAPH—INDUCED CURRENTS—MAGNETO-ELECTRICITY AND THERMO-ELECTRICITY.

255. Electro-metallurgy, or the art of working in metals by electricity, is divided into three branches, viz: 1, Electro-typing; 2, electro-plating and electro-gilding; 3, the separation of metals from their ores by electrical currents. This latter branch of electro-metallurgy has, however, been but imperfectly worked out, although in all probability the formation of *metallic veins* and *lodes* in rocks is in many cases due to the persistent action of *earth currents.*

256. Electro-typing is the process by which copies or facsimiles of medals, statuettes, engraved plates, and other objects of art or utility are made in compact metal (usually copper), through the agency of the electric current. The electricity used for this purpose is usually derived from a Voltaic or a magneto-electric battery.

All that is necessary to conduct this process on a small scale is an electro-typing or *precipitating trough* and a single *Daniell's cell,* similiar to those shown in fig. 134. The precipitating trough being charged with a concentrated solution of *copper sulphate,* the plaster of Paris medallion, or other article to be electro-typed, is connected by a wire with the *zinc* plate, and a piece of sheet copper with the *copper* of the Daniell's Voltaic couple, both articles being suspended in the copper sulphate solution by the cross pieces as in the case of *electro-plating,* shown in fig. 145.

A *weak* but *constant* current of Voltaic electricity is thus passed through the solution by which the copper sulphate is decomposed, the *copper* being deposited on the surface of the medallion or mould which has thus become the *negative* electrode of the Voltaic couple, its place in the solution being taken by *fresh copper* dissolved from the substance of the copper plate, which has thus become the *positive* electrode.

The process of *electrolysis* by which these changes are

effected is precisely similar to that which has been previously explained as taking place in the working of a Daniell's couple. (See Arts. 220 and 233).

257. To Prepare a Plaster Cast for Electro-typing.—(1.) Place a saucer or plate containing a small quantity of *white wax* over a saucepan of boiling water. (2.) When the wax is melted, place the plaster medallion in the liquid wax (which should not be more than one-fourth of the depth of the medallion), and allow it to remain there until it has become quite *saturated* with the melted wax, which is easily known by its edges and face assuming a uniformly darker and greyer tint. (3.) Now remove the saturated plaster medal, cool, when it will assume a beautiful *ivory*-like appearance; black-lead the surface and edges by rubbing them over with a soft hair pencil, charged with finely powdered black-lead, by means of which it thus acquires the *conducting* surface essential to success in the process. (4.) Bend wire round the edge, and connect with *Voltaic* cell and *precipitating trough* as previously described.

Care should be taken that the *black-leading* should not extend round the edge to the back of the medal, or it will prevent the removal of the electro-type from the cast.

The process of electro-typing is a cheap, and to young people in general, a most interesting, amusing, and instructive recreation.

258. Electro-plating is the process by which articles, as forks, spoons, etc., manufactured in the cheaper metals, are covered with a thin *deposit* of pure *silver*, so as precisely to resemble objects in *solid* silver. The process, though *theoretically* simple, is attended with practical difficulties, which can only be overcome by much skill and experience. The process itself really consists in *electro-typing* in *silver* instead of *copper*.

To electro-plate a German-silver, copper, or brass fork, or other object—(1.) Prepare a *silvering bath* in the vessel A (fig. 145), consisting of 1 part of *cyanide of silver*, 1 of *cyanide of potassium*, dissolved in 100 parts of *water*. (2.) Suspend (in the solution) from the cross-piece (B) the article to be *electro-plated*. (3.) From the cross-piece (C) suspend a plate of *pure* silver (D), which must be connected with the wire going to the *copper* plate of the

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Care should be taken that the *black-leading* should not extend round the edge to the back of the medal, or it will prevent the removal of the electro-type from the cast.

The process of electro-typing is a cheap, and to young people in general, a most interesting, amusing, and instructive recreation.

258. Electro-plating is the process by which articles, as forks, spoons, etc., manufactured in the cheaper metals, are covered with a thin *deposit* of pure *silver*, so as precisely to resemble objects in *solid* silver. The process, though *theoretically* simple, is attended with practical difficulties, which can only be overcome by much skill and experience. The process itself really consists in *electro-typing* in *silver* instead of *copper*.

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battery—the *silver plate* thus becomes the *positive* electrode of the battery.

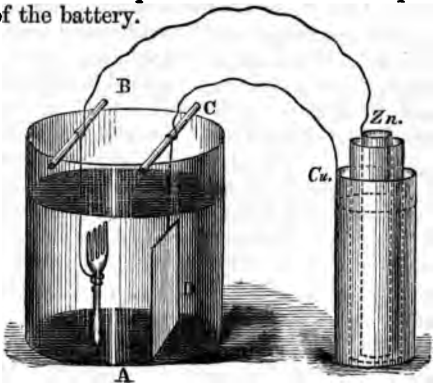

Fig. 145.—Electro-plating Apparatus.

A, Glass or earthenware cell.
B, Cross-piece supporting the article to be electro-plated, or *positive* metal which is connected by a wire with the *zinc* cylinder of the Daniell's element. A metal hook here forms the *negative* electrode.
C, Cross-piece supporting the silver-plate, which being connected with the *copper*-plate of the Daniell's cell, forms the *positive* electrode; the article to be plated, which must be connected with the *wire* going to the *zinc* of the Daniell's cell, thus becomes its *negative* electrode.
Cu the copper, and *Zn* the zinc element of a Daniell's cell.

The Voltaic current thus, as it were, *carries* the silver over from the plate (D), and *deposits* it on the surface of the *fork;* what really takes place being the gradual *loss* by *electrolysis* of the silver in solution, which is deposited on the surface of the fork, and is immediately *replaced* by silver from the substance of the plate, which thus gradually disappears.

259.* Electro-gilding.—The process of electro-gilding is conducted on precisely the same principles as those of electro-plating (electro-silvering), the solution used in the precipitating cell consisting usually of some *alkaline* solution of gold. The surfaces of the articles to be gilded have

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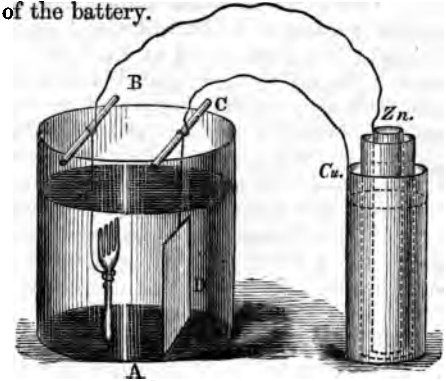

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259.* Electro-gilding.—The process of electro-gilding is conducted on precisely the same principles as those of electro-plating (electro-silvering), the solution used in the precipitating cell consisting usually of some *alkaline* solution of gold. The surfaces of the articles to be gilded have

effected is precisely similar to that which has been previously explained as taking place in the working of a Daniell's couple. (See Arts. 220 and 233).

257. To Prepare a Plaster Cast for Electro-typing.—(1.) Place a saucer or plate containing a small quantity of *white wax* over a saucepan of boiling water. (2.) When the wax is melted, place the plaster medallion in the liquid wax (which should not be more than one-fourth of the depth of the medallion), and allow it to remain there until it has become quite *saturated* with the melted wax, which is easily known by its edges and face assuming a uniformly darker and greyer tint. (3.) Now remove the saturated plaster medal, cool, when it will assume a beautiful *ivory*-like appearance; black-lead the surface and edges by rubbing them over with a soft hair pencil, charged with finely powdered black-lead, by means of which it thus acquires the *conducting* surface essential to success in the process. (4.) Bend wire round the edge, and connect with *Voltaic* cell and *precipitating trough* as previously described.

Care should be taken that the *black-leading* should not extend round the edge to the back of the medal, or it will prevent the removal of the electro-type from the cast.

The process of electro-typing is a cheap, and to young people in general, a most interesting, amusing, and instructive recreation.

258. Electro-plating is the process by which articles, as forks, spoons, etc., manufactured in the cheaper metals, are covered with a thin *deposit* of pure *silver*, so as precisely to resemble objects in *solid* silver. The process, though *theoretically* simple, is attended with practical difficulties, which can only be overcome by much skill and experience. The process itself really consists in *electro-typing* in *silver* instead of *copper*.

To electro-plate a German-silver, copper, or brass fork, or other object—(1.) Prepare a *silvering bath* in the vessel A (fig. 145), consisting of 1 part of *cyanide of silver*, 1 of *cyanide of potassium*, dissolved in 100 parts of *water*. (2.) Suspend (in the solution) from the cross-piece (B) the article to be *electro-plated*. (3.) From the cross-piece (C) suspend a plate of *pure* silver (D), which must be connected with the wire going to the *copper* plate of the

battery—the *silver plate* thus becomes the *positive* electrode of the battery.

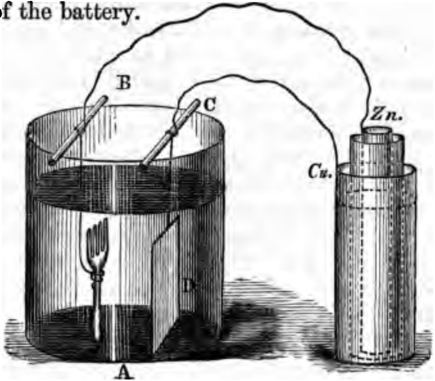

Fig. 145.—Electro-plating Apparatus.

A, Glass or earthenware cell.
B, Cross-piece supporting the article to be electro-plated, or *positive* metal which is connected by a wire with the *zinc* cylinder of the Daniell's element. A metal hook here forms the *negative* electrode.
C, Cross-piece supporting the silver-plate, which being connected with the *copper*-plate of the Daniell's cell, forms the *positive* electrode; the article to be plated, which must be connected with the *wire* going to the *zinc* of the Daniell's cell, thus becomes its *negative* electrode.
Cu the copper, and *Zn* the zinc element of a Daniell's cell.

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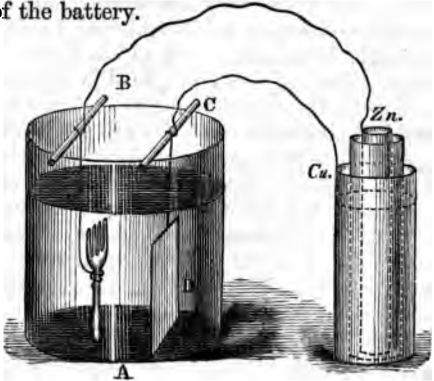

Fig. 145.—ELECTRO-PLATING APPARATUS.

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C, Cross-piece supporting the silver-plate, which being connected with the *copper*-plate of the Daniell's cell, forms the *positive* electrode; the article to be plated, which must be connected with the *wire* going to the *zinc* of the Daniell's cell, thus becomes its *negative* electrode.

Cu the copper, and *Zn* the zinc element of a Daniell's cell.

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APPENDIX.

1. **To make a Glass Tube for Excitation.**—Length, say 18 inches; diameter, 1 inch; one end closed and rounded, the other end fused.

2. **To make Amalgamated Silk Rubber.**—Black silk, double and stitch; amalgam and tallow.

3. **To make Pointed Support.**—Blanket pin pushed through a bung.

4. **To make a Glass Needle with Socket.**—Close one end of glass tube entirely, other end nearly; balance on file; scratch centre; soften and push in with point.

5. **To make two Proof-Planes, one with Glass Socket.**—Varnished strip of glass; cut card into two circles, 2 inches in diameter, and gilt paper likewise, fasten with gum; make socket of glass tube, and attach to one strip bent in centre.

6. **To make Insulated Table.**—Stout zinc disc, 4 inches diameter; support by varnished glass rod, 6 in. high, fastened in wood block.

7. **To make Conducting Cone Cylinder.**—Cardboard (quarter sheet), roll into cone and fasten with sealing-wax; cover with gilt paper; stand on insulating support; do likewise for cylinder.

8. **To make Spherical Conductor.**—Florence flask or wood-ball covered with tin-foil; cork in neck, fasten with plenty of shell-lac to edge of square board.

9. **To make Condenser.**—Varnish sheet of glass, 10 inches by 7 inches, both sides; attach silk handles with sealing-wax; cut two pieces of tin-foil, 7½ inches by 5 inches each.

10. **To make a Voltameter.**—Cut off shank of 4-inch funnel to within ¾ inch of neck; solder strip of platinum foil, 1 inch by ¼ inch, on to each of two covered copper wires, 6 inches long; pass wire through cork in shank of funnel; mix plaster of Paris and water into thin paste, and pour in to within 1½ inch of the top; bore hole size of shank of funnel in centre of 1-inch thick board, 6 inch by 4 inch, and two holes for wires to pass through near edge of board; fix funnel in hole with plaster of Paris, and bring wires under board and up through holes; solder ends of wires to slips of brass, 1 inch by ¼ inch, which fix to board, to serve purpose of binding screws; pour a little melted resin over

plaster in funnel, so as just to cover soldered joints of platinums; make two glass tubes closed at one end 5 inches by ½ inch (or use two test tubes); fill funnel and tubes with water containing a little sulphuric acid, and invert tubes over platinums; if time allows, fix upright of wood, 9 inches high, beside funnel, with two brass wire arms to hold tubes.

11. **To make Astatic Galvanometer.**—Wind copper wire on wood frame, remove wood and varnish wire; fix coil on round wood block, leaving projecting ends, which solder to hard brass strips; screw these latter to wood block to serve purpose of binding screws; bend stout brass wire into arch, and fix firmly into block; make small bend in centre of wire, and fasten cork therein; push straight piece of brass wire, 2 inches long, through cork; magnetize two sewing needles, and fix (with opposite poles adjoining), ½ inch apart, by means of twisted fine copper wire; suspend needles by silk fibre; attach fibre to lower loop in brass wire, which passes through cork; cut card into circle, 4 inches diameter, and graduate circumference into degrees; place (but not fix) card in proper position over coil by means of two corks cemented to board; make needles as far as possible astatic; draw out fibre of glass, and fix to upper needle; place needles within coil, and adjust to proper height by sliding wire; cover all with glass shade.

12. **To amalgamate Zinc for Battery Plate.**—Dip zinc plate into dilute sulphuric acid; pour a little mercury in plate; wrap tow round end of stick, and rub mercury over zinc.

13. **To make two Bar Magnets.**—Two strips of steel, each 4 inches long; cut ends square and clean; magnetize by drawing one end of bar magnet along each; note polarity produced; demagnetize one strip, and remagnetize in reverse direction.

14. **To magnetize two Horse-shoe Magnets.**—Place two steel horse shoes end to end, marking one pole of each; draw horse-shoe magnet, held vertically, completely round and round the system, always preserving same advancing pole, and beginning and ending stroke at one of the bends; note poles produced, and how produced.

15. **To obtain Magnetic Curves.**—Place pair of bar magnets on white paper and sheet of glass above; sprinkle iron filings from muslin over glass and tap surface; try in this way various combinations of poles with bar and horse-shoe magnets.

16. **To fix Magnetic Curves.**—(*a*) Make a solution of gall nuts; brush over sheet of paper with solution, remove superfluous moisture by blotting paper; place damped paper over curves, press evenly, carefully lift paper, dry quickly, and shake off filings; a permanent impression in ink will be left on the paper. (*b*), Fix pair of magnets to one side of square of glass, coat other side with very thin gum-water; when plate is quite dry, dust fine iron filings

over gummed surface, tap, then breathe gently on plate; gum is thereby softened, and curves fixed.

17. To make Horizontal Magnetic Needle.—Soften strip of steel in centre, drill hole, make glass cap and cement on to steel, balance on pointed support, magnetize strip, mark ends with red and blue paper.

18. To make Vertical Magnetic Needle. — Drill hole through second strip of steel, as before; fasten pin through hole; make arms of wire for needle to play in; attach handle.

19. To make a Current Reverser.—Block of wood, 4 × 2½ inches; cut out three holes for mercury, ¼ inch diameter, at one end of wood, and two holes at other end; cross-piece of thick copper wire fixed from hole one to three; two movable thick copper wires, with ends bent down, and fixed to wooden lid 3 × 1½ inch.

20. To make a Simple Discharger.—Gutta-percha covered wire 8 inches long; take off 3 inches of covering at each end, and cast on lead bullets.

21. To make a Leyden Jar with Movable Coating.—Paste a piece of tin-foil, 8 inches by 15 inches, on card; clean and dry the jar; cut stiffened foil into two strips, 4 inches wide, and cut off from each strip length fully sufficient to go round the jar; make outside and inside cylinders, using surplus pieces to form bottoms; cut two strips of card (tin-foiled), 3½ inches by 1 inch, bend ends, and paste across top and bottom of inside cylinder at right angles to each other; cast lead bullet on brass wire, 9 inches long; pass wire through upper cross-piece of card, and attach to lower cross-piece by a cork; varnish outer exposed surface of glass jar.

22. To make an Electrophorus.—Cut zinc disc, 6 inches diameter; make a socket of zinc, and fit varnished glass handle by shell-lac; excite sheet of varnished glass.

23. To make arrangements for Lighting Gas by a Spark.—Glass tube, 6 inches long, drawn out to point, and bent at right angles; attach copper wire, and bend over jet; fasten second short piece of copper wire to insulating support.

24. To make a Faraday's Gauze Bag for showing Electric Distribution.—Bend brass wire into circle, 5 inches diameter, leave projecting piece, and fix into varnished glass handle; sew muslin into cone, and attach to brass ring; fix silk thread to end of cone; fix glass stem into wooden block.

25. To make a Daniell's Cell.—Roll brown paper five or six times round glass tube, 1 inch diameter; cement edge of paper with shell-lac, and close bottom by cork; bend copper sheet, 4 inches by ¾ inch, to go inside paper cell; bend zinc sheet, 4 inches by 4 inches, to go outside; solder three inches copper wire to zinc and copper; fit up cell, and pour solution and crystals of sulphate of copper into inner cell, using salt water in outer.

26. To make a Right and Left-Handed flat Helix.—Cut two circles of stout card, 4 inches diameter; fasten a cork to the centre of each, and pass a slender axis of wood through the centre of the corks and card; the corks being outside, push the card discs together until about ¼ inch apart. Through a hole in the card, beside the cork, previously pass the end of the covered wire given you; wind the wire round and round the axis till a sufficiently large spiral is made; holding the ends of the wire, remove the free card, gum a circular piece of paper, and place over spiral; when the paper is dry the spiral will be fixed, and hence the other cork can be removed; proceed in the same for helix, wound in the opposite direction.

27. To make a Current Reverser for Telegraphic purposes.—Cut strip of hard brass, ½ inch wide, into two pieces (A and B), each 3 inches long, one piece (C) 2 inches, and one (D) 1¾ inch; solder D across end of C, so as to make T-piece; upon a stout block of wood, 2½ inches by 4 inches, screw one end of A and B, so that the strips may be parallel, and 1 inch apart; midway between A and B, and ½ inch inward, screw end of T-piece; beneath free extremities of A and B, bore two holes for thick copper wire, staple driven in from below, leaving ends projecting ¼ inch; carry a wire from copper staple to one side of block of wood, and a second wire soldered to end of T-piece to other side; adjust brass strips, so that cross-piece of T is ½ inch above board, and free ends of A and B spring up against it; to the fixed ends of A and B join up galvanometer wires, battery wires to the right and left of block; the battery contact is made when either A or B is depressed.

28. To make a Single Needle Telegraph.—Wind two coils, similar to those of galvanometer, leaving 6 inches of projecting ends; fasten coils to one end of thin upright of wood, 5 inches by 3 inches (stout cardboard, doubled over to form a little roof, is a good substitute for the wood); make vertical needle to move within coils, and index outside moving between stops; carry wires to current reverser, just described.

29. Prove that Electric Attraction is not Selective nor Directive, and is therefore unlike Magnetic Attraction. — Suspend light bodies, rubbed glass, shell-lac, electric needle; note position of rest and attraction by all neutral bodies.

30. Prove the Dual Nature of Electricity, and show that it is therefore unlike Gravitation.—Determine the Fundamental Law. Rubbed glass near suspended glass, then near rubbed shell-lac.

31. To determine Relative Distribution of Electricity on Surface

of Cone, and without and within Cylinder.—Cone, cylinder, electroscope, proof-plane, insulating table, and rubbed glass.

32. To Charge Electroscope by Induction (1) Transiently, (2) Permanently. To examine Quality in each case.—Rubbed glass rod, electroscope; rubbed shell-lac; carrier.

33. To prove that both Electricities are generated by Induction.—Rubbed glass; conductor hung by silk; examine near and distant face by carrier and electroscope.

34. To show that Repulsion is the only True Test of both Bodies being Electrified.—Attract charged lath by fingers; repel charged lath by similarly-charged body.

35. To test Delicacy and determine Zero of Astatic Galvanometer.—Solder wires to end of a pin and a needle; join up to galvanometer; push couple through cork, so as to expose ½ inch of each metal; dip into salt water, in wine glass, and note deflection; reverse current, and again note deflection; repeat once or twice; take mean of difference of deflections, and move zero of card accordingly; now fix card in this position.

36. Try production of Electricity by Hot Coal dipped in Water.—Gold-leaf electroscope, water in metal dish (lid of tin canister) on insulating stand, wire to electroscope, drop hot coal in water.

SPECIMEN EXAMINATION PAPER (1876).

GENERAL INSTRUCTIONS.

If the rules are not attended to, the paper will be cancelled.

You are permitted to answer questions from the Elementary Paper, or from the Advanced Paper, or from the Honours Paper, but you must confine yourself to one of them.

In all cases the number of the question must be placed before the answer on the worked paper.

Three hours are allowed for this paper.

FIRST STAGE OR ELEMENTARY EXAMINATION.

INSTRUCTIONS.

You are only permitted to *attempt eight* questions.

You may select only *two* in magnetism, *three* in frictional electricity, and *three* in Voltaic electricity.

The value attached to each question is the same.

Magnetism.

1. You possess a small magnetic needle, with the end which points to the north marked N., and that which points to the south marked S. An iron poker which has been perfectly annealed is placed upright, and the magnetic needle is brought first near the bottom of the poker, and then gradually raised past the centre to the top. The poker acts upon the needle, and you are required to describe its action. (I must be sure that you understand what is meant by a perfectly annealed iron poker.)

2. Near a ball of perfectly annealed soft iron, the north end of a strong steel magnet is placed. What is the action of the magnet upon the ball? What change occurs in the ball when the magnet is withdrawn; and what occurs when the south pole of the magnet, instead of the north, is placed near the ball? Illustrate your answers by diagrams.

3. A long strip of hard steel is magnetised, and, when your small magnetic needle is passed along the strip, its north point is attracted by one end of the strip, its south point by the other, the centre of the strip appearing to attract neither point of the needle. When the strip is broken across at the centre, what is the action of its two halves upon the magnetic needle?

4. What is meant by the terms *declination* and *inclination* as applied to magnetism?

Frictional Electricity.

5. What is meant by the terms *conduction* and *insulation* as applied to frictional electricity? Describe an experiment which shall illustrate the properties of metal wire, common twine, and a silk string, as regards conduction and insulation.

6. A sheet of hot paper is placed on a hot board, and india-rubber is passed briskly over it. Two strips are cut from the paper and held up close and parallel to each other. How will they act upon each other? A glass rod, rubbed with silk, repels both the strips; what is the inference?

7. Describe and explain the action of the common gold-leaf electroscope.

8. An apple held in the hand and struck with a fox's brush shows no signs of electrical action; suspended by a string of silk and struck with the brush it becomes electrified, attracting light bodies and causing the leaves of the electroscope to diverge. Explain these results.

9. A stout stick of sealing-wax is stuck upright to a piece of wood acting as a base; into the wax at the top is inserted a needle, and on to the needle is fixed an apple. Near to the apple, but not into contact with it, is brought a rod of glass which has been rubbed by silk. What is the condition of the apple while the rod remains near it? What occurs when the apple is touched for a moment? What finally occurs when the rubbed glass is withdrawn?

Voltaic Electricity.

10. Amalgamated zinc plates are employed in Grove's Voltaic Battery. How are the plates amalgamated, and what useful purpose does the amalgamation serve?

11. A plate of platinum and a plate of amalgamated zinc are immersed in water, rendered sour by sulphuric acid. Describe accurately and explain what is observed both before and after the plates are caused to touch each other.

12. Describe and explain the ordinary multiplying galvanometer.

13. A steel fork and a steel knife are connected by wires with a galvanometer. The knife and fork are used to cut a juicy and well-salted beefsteak, what will be the effect upon the galvanometer? What will be the effect when a silver fork is substituted for the steel one, the steel knife being retained?

14. A current flows through a telegraph wire between Edinburgh and London, but we do not know whether it comes from Edinburgh or from London. Supposing this knowledge desired, how would you obtain it?

MAGNETISM (ELEMENTARY STAGE), 1867-1875.

1867.

1. I have two pieces of the same steel, of equal size, shape, and hardness; one piece is a magnet and the other not. State fully the particulars in which they differ from each other.

2. People sometimes say that "the earth is a magnet." What do they mean?

3. How do magnetic poles act upon each other? What do you understand by a magnetic pole?

4. How does the middle of a magnet act upon a piece of iron? How do the ends of the magnet act upon the same iron? Does any change occur in the iron when the magnet acts upon it?

1868.

5. You are provided with a steel sewing needle and are required to magnetise it so as to render its point a south pole; how will you do it?

6. State what you know regarding the use of the magnetic needle in the steering of ships.

7. A magnet has two poles near its two ends; supposing it to be broken across at the middle, what would be the condition of the two halves?

8. What do you mean by the magnetic meridian? Does a magnetic needle in London point exactly north and south; if not, how would you name the angle enclosed between the magnetic and the geographical meridian?

1869.

9. You are to examine, by means of a magnetic needle, the magnetic condition of a piece of soft iron. You are also to examine the condition of a piece of magnetic iron ore of the same size and shape as the iron. State some of the differences which are sure to show themselves between both.

10. How do you figure to yourself the change that occurs in a bar of unmagnetised steel when the pole of a magnet is rubbed along it? What do you understand by the pole of a magnet?

11. Supposing the top of the page on which you are writing to represent the north, and the bottom to represent the south, you are required to draw the true geographical meridian. Then to draw a magnetic needle in the position which it occupies with reference to that meridian, and to mark on your figure the angle of declination and the number of degrees it embraces in our latitude. Why do I use the words "our latitude?" Give also a sketch of the dipping needle, and name the angle that it makes with the horizon.

1870.

12. What is the difference between iron and steel as regards their acceptance and their retention of the magnetic condition?

13. Sketch a bar-magnet and letter its poles. Show by dotted lines the manner in which iron-filings arrange themselves round the bar-magnet. Do the same for a horse-shoe magnet.

14. What do you think causes a magnetic needle to set north and south? Does its direction ever vary? if so, state what you know regarding the variation.

1871.

15. Tell me what you know about the loadstone or natural magnet.

16. Describe how you would impart the magnetic power of the loadstone to a piece of steel.

17. What is meant by the declination and inclination of the magnetic needle? What is meant by the terms magnetic dip, magnetic poles, and magnetic equator?

18. Give your reason for supposing that the earth is a large magnet.

1872.

19. A magnet is broken into two, describe the magnetic conditions of its parts.

20. State the grounds of the belief that the smallest particles of a magnet are themselves perfect magnets.

21. The marked end of a magnet is attracted by the earth's north magnetic pole; but if the magnet be set floating on a cork it does not move towards the pole. Why?

1873.

22. A steel needle is drawn over the N. pole of a magnet, from eye to point; what is the state of the needle? The point is set to the N. of a compass needle; what occurs?

23. Break the needle in two, and present the two ends of each half in succession to the end of a mariner's compass needle; what occurs?

24. What is the polarity of a magnet?

25. Carry a dipping needle from the earth's N. magnetic pole across the equator to the S. pole; how will the dipping needle behave?

1874.

26. In what direction does the mariner's compass point in London?

27. Can you obtain a magnet with a single pole? Give the experimental grounds of your answer.

28. You are required to magnetise a sewing needle so as to make the eye end of the needle a north pole: how will you do it?

29. You are required to demonstrate the law that like magnetic poles repel, and that unlike poles attract each other: how will you do it?

1875.

30. What is the meaning of the term geographical meridian? What is the meaning of magnetic meridian? What name is given to the angle between the two meridians?

31. A bar-magnet, freely suspended horizontally, sets in the magnetic meridian. Supposing a second bar-magnet to be suspended by the side of the first, how will they act upon each other? Make your answer clear by a diagram.

32. The pole of a magnet is drawn over an unmagnetized bar of steel; state in the language of the theory of magnetic fluids what occurs.

33. State what is known to you regarding the difference between iron and steel, as regards the acceptance and retention of magnetism.

FRICTIONAL ELECTRICITY (ELEMENTARY STAGE), 1867-1875.

1867.

1. We often hear of an "electric fluid." What are your notions regarding it?

2. If asked to show some of the elementary effects of electricity, how would you do it?

3. How is electricity stored up in the Leyden jar?

4. We hear of frictional electricity and of Voltaic electricity, what is the difference between them? Describe the way in which both of them may be obtained.

5. What are lightning conductors? and how do they act in averting danger from lightning?

1868.

6. What is meant by the term insulated? I bring a glass rod which has been rubbed with silk near an insulated brass sphere; what is the condition of the sphere while the glass is near it? What occurs when the glass is removed?

7. If you take an insulator in your hand and rub it properly you electrify it; if you do the same with a conductor you obtain no signs of electricity; what is the reason? Bodies were formerly divided into electrics and non-electrics; why?

8. Explain in accordance with the theory of electric fluids the attraction of light bodies by an electrified glass rod.

9. Describe and explain the original experiment which led to the discovery of the Leyden jar.

10. Describe some one form of the electric machine, and explain its use.

1869.

11. An electrified body is brought near a scrap of paper or of gold leaf resting on a metallic surface, what happens to the scrap, and what is its exact electrical condition when it is attracted? Supposing it to rest on a surface of shell-lac, what would be its condition when attracted by the electrified body?

12. Describe the gold-leaf electroscope, and state the principle of its action.

13. I grind sulphur in a mortar, and thus electrify it. I place some of the electrified powder on the plate of a gold-leaf electroscope; the leaves diverge; why? since the sulphur is an insulator, and does not part with its electricity. I remove the powder by means of an insulator; what will occur, and why will it occur?

14. I place a sheet of vulcanized india-rubber on a sheet of tin-foil, and a second sheet of tin-foil upon the rubber. I connect the lower sheet with the earth, and the upper one with the conductor of an electrical machine; what occurs when the machine is set in action?

1870.

15. I wish you to show me a few simple electric effects? how will you do it?

16. I wish you to prove that like electricities repel each other, and that unlike electricities attract each other; but you are first to state what image you have in your mind when you speak of electricity at all.

17. Do you know what electrical induction is? If so, describe an experiment which shall illustrate it.

18. A Leyden jar is hung up in the air by a silk string; the knob of the jar is connected with an electric machine, and its outer coating is connected by a wire with a large gas-pipe. What occurs in this outer wire when the machine is worked? and why does it occur?

19. Why do I employ a silk string to suspend the jar in the last experiment? What would happen supposing the string to be ordinary twine? Let your answers be as clear and complete as possible.

1871.

20. If you rub a stick of sealing-wax held in the hand with flannel it becomes electrified; if you rub a rod of brass you do not electrify it. What is the reason of this difference?

21. When you think of an electrified body, in what way do you picture it in your mind?

22. Give a sketch of the theory of electric fluids.

23. When you rub a stick of sealing-wax with flannel, what is the state of the rubber? When you rub a stick of glass with silk, what is the state of the rubber?

24. How do you suppose thunder and lightning to be produced?

1872.

25. If upon a warm board a dry sheet of paper be rubbed with india-rubber it is electrified. How is this proved?

26. Show by a simple experiment that the electricity developed on resin by the friction of flannel is different from that developed on glass by the friction of silk.

27. Describe Franklin's Plate, and explain its action.

28. A strip of paper rubbed with india-rubber is brought near a glass rod which has been rubbed with silk; what follows? Deduce from the experiment the quality of the electricity upon the paper.

29. Explain fully what takes place when light bodies are attracted by a stick of sealing-wax rubbed with flannel.

1873.

30. Hold a dry glass rod, rubbed with silk, near a brass ball, on a dry glass stand; what is the state of the ball? If the stand be moist, what will occur?

31. Test whether two strings insulate or conduct electricity.

32. Two brass balls, on glass stands, are united by a chain; sealing-wax rubbed by flannel is brought near one; what is the condition of the other?

33. Touch the ball furthest from the wax, remove your hand, and then the wax; what is now the condition of the two balls and chain? What occurs at each step?

34. How will you charge and discharge a Leyden jar?

35. Rub sealing-wax with flannel; are both kinds of electricity excited? If both, where? If only one, where?

1874.

36. A collodion balloon simply stroked with the hand becomes negatively electrified. Supposing you were asked to prove the truth of this statement how would you proceed?

37. An egg shell is placed on a table, and a glass rod which has been rubbed with silk is brought near the shell: the shell rolls after the rod. Describe the condition of the rod and the shell during the motion of the latter.

38. You are required to prove by experiment the electrical law that bodies similarly electrified repel; and that bodies dissimilarly electrified attract each other: how will you do it?

39. Describe the Leyden jar, and the mode of charging it.

40. Describe the electrophorus and the mode of charging it.

1875.

41. From what is the word electricity derived? Describe the substance with which the first electrical effects were observed, and describe also the mode of exciting it.

42. You are required to electrify strongly a glass tube; how will you do it? You are required to electrify strongly a tube of gutta-percha; how will you do it?

43. What is the action of two electrified glass tubes upon each other? What is the action of two electrified gutta-percha tubes upon each other? What is the action of an electrified glass tube upon an electrified tube of gutta-percha?

44. I stick a bit of sealing-wax against a penny or a half-crown; and I whisk a bit of vulcanized india-rubber with a fox's brush. Holding the sealing-wax as a handle, I lay the penny, or half-crown, flat on the india-rubber. What is the condition of the coin? I touch the coin, what occurs? I lift it by the handle, what is its condition?

45. You are required to explain, in accordance with the theory of electric fluids, how light bodies are attracted by a glass rod positively electrified, and by a gutta-percha tube negatively electrified.

VOLTAIC ELECTRICITY (ELEMENTARY STAGE), 1867-1875.

1867.

1. Supposing that you had a current of Voltaic electricity at your disposal, tell me how you could apply it in the way of exciting magnetism.

2. How could you apply the current in the way of producing chemical action?

3. Describe the chemical action which goes on in the Voltaic cell itself. You must, of course, here describe the particular cell you have in view.

4. What do you understand by a Voltaic circuit?

5. I find, on closing a Voltaic circuit, near which a small compass is placed, that the needle always moves at the moment the circuit is closed; it also moves at the moment the circuit is opened. State what you know regarding these effects.

6. If the same electric current be sent through a silver wire and an iron wire of the same thickness, the iron wire will become hotter than the silver. Why?

1868.

7. If you wanted to prove that an electric current acts upon a magnetic needle, give me a clear statement of how you would proceed.

8. What do you understand by an electric current?

9. Describe and illustrate by a sketch how water may be decomposed by an electric current.

10. A coil of wire is placed north and south upon a table: an electric current is sent through the coil, which, to a person placed at the south end of the coil, circulates in the direction of the hands of a watch; what is the magnetic condition of a bar of iron placed within the coil?

11. Describe a cell of Grove's battery.

12. You have the materials for a battery of five cells of Grove's construction: describe fully how you would put them together so as to set the battery in action.

1869.

13. A steel knife and a silver fork are plunged into the same orange: what occurs when the metallic portions of both are united?

14. Water is a part of the juice of the orange; how do you suppose the water to be acted on when the two metals in the last experiment are connected together? You must here state the composition of water, both by weight and volume.

15. You are required to charge a cell of Grove's battery. How will you do it?

16. To two points of a telegraph wire 50 feet apart I attach the two ends of a second wire 60 feet long. The two wires being kept asunder, how will an electric current act when it reaches their junction? Your answer here must be full.

17. A telegraph wire runs north and south along the magnetic meridian. A magnetic needle free to turn in *all* directions is placed *beside* the wire, and on the same level with it. How will this needle act when a current is sent through the wire from south to north? Supposing the wire to run east and west, how would you detect the direction of a current passing through it?

1870.

18. I wish you to produce an electric current; how will you do it? Can you see, feel, or taste this current? If not, what proof have you of its existence?

19. You have a Voltaic cell containing a plate of platinum and a plate of zinc, and, as liquid, dilute sulphuric acid. What occurs in the liquid when the two metals are united? Does anything occur that you can actually see?

20. You are required to make a strong electro-magnet; how will you proceed? In what particulars does an electro-magnet differ from an ordinary steel magnet?

21. Who was Volta? Who was Galvani? Why do we hear sometimes of Voltaic electricity, and sometimes of galvanic elec-

tricity, or galvanism? Is there any difference between Voltaic and galvanic electricity?

22. You are required to fire gunpowder by means of a Voltaic current; how will you make the experiment?

1871.

23. I dip a strip of pure platinum and pure zinc into water which has been rendered sour by sulphuric acid. State what occurs when the metals do not touch each other, and also what occurs when they do touch each other.

24. Supposing the two strips to be half in the sour water and half out of it, and that their two outer ends are united by a wire, what occurs?

25. Supposing the wire that connects the two ends to be dipped into iron filings, what occurs? Supposing it to be coiled round an iron poker, what occurs?

26. If the wire be placed over a freely suspended magnetic needle; tell me exactly what occurs.

1872.

27. If a strip of pure platinum and pure zinc be immersed in acidulated water, and caused to touch each other, bubbles of gas are seen rising from the platinum, but none from the zinc. Explain this effect.

28. You are required to prove that a current of electricity is passing through a telegraphic wire to which you have access. How would you do it?

29. If a strong Voltaic current is sent in succession through a thin platinum wire, through acidulated water, and then through a wire which surrounds a common poker, what is the effect produced in each case?

30. What is the part played by nitric acid in Grove's battery?

31. Explain what you understand by the direction of a Voltaic current?

1873.

32. Place silver on the tongue, and zinc under it, so that the two pieces touch; what occurs? Prove that an electric current is generated.

33. A Voltaic current is sent through water, which is decomposed; what two gases are found, and where do they appear?

34. What flows in the Voltaic current; anything you can see, feel, taste, or smell? If not, what proof of its existence?

35. Sketch a cell of Grove's battery, and give the use of its parts.

36. The same current from a Grove's battery is sent through silver, and platinum wire, of the same length and thickness. The silver is cool, the platinum heated. Why?

1874.

37. Tell me what you understand by chemical combination and chemical decomposition, illustrating your answers by reference to the formation and decomposition of water.

38. Give me a good example of chemical combination and decomposition brought about by one and the same Voltaic current.

39. What is your notion of a Voltaic current?

40. Give me a clearly described example of the magnetic action of an electric current.

41. I give you platinum, zinc, and brine, and ask you to produce by means of them an electric current: how will you do it?

1875.

42. You are required to generate a Voltaic current; how would you do it? How would you prove that you have really succeeded in producing a current?

43. State what you know regarding the substances oxygen and hydrogen. How would you mix them, and deal with them, so as to form water? How would you reduce that water again to oxygen and hydrogen by a Voltaic current.

44. A current passes in a telegraph wire from south to north; you bring a magnetic needle, suspended horizontally, under the wire; what effect will be observed?

45. How are wires carrying a Voltaic current usually insulated? What is the meaning of insulation?

46. Suppose you wind an insulated wire round a poker, and send a Voltaic current through the wire, what occurs? What will be the difference between the condition of the knob and of the other end of the poker?

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